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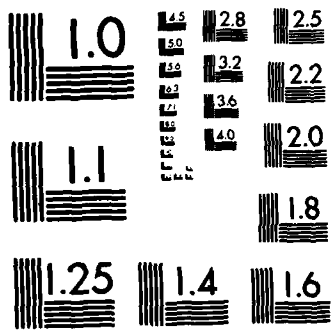

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DEPARTMENT OF DEFENSE
WEAPON SYSTEM ACQUISITION POLICY:
A SYSTEM DYNAMICS MODEL AND ANALYSIS

Edward L. Whittenberg, Captain, USAF
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LSSR 13-82

DEPARTMENT OF THE AIR FORCE
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A dynamic policy model of the DoD acquisition system has been developed and tested. The model provides a broad-based structure of the weapon acquisition system that can be used as a base for the testing and evaluation of alternative acquisition policies. Sources of information used in model development include both literature research and personal interviews with DoD, Air Force, Congressional, and OMB personnel active in the operation and analysis of the acquisition system. The model structure is built around a system goal of providing approximate parity in total capability, in the aggregate, of operational US and Soviet weapon systems. Emphasis is placed on the dynamic relationships within the acquisition system and how they are impacted by DoD policy and external pressures. Use of the model for policy analysis provides information on trends within the acquisition system as policy implementations or changes are tested.

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DEPARTMENT OF DEFENSE WEAPON SYSTEM ACQUISITION POLICY: A SYSTEM DYNAMICS MODEL AND ANALYSIS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirement for the

Degree of Master of Science in Systems Management

By

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This thesis, written by

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and

Captain Alan H. Woodruff

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements of the degree of

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PREFACE

This thesis reports on the development of a system dynamics model of the Department of Defense weapon acquisition process and its environment. The authors recognize that there are several categories of people who may read this thesis, and wish to provide a general guide to the thesis for the various audiences.

Anyone who is interested in a summary of the research, without a desire to understand all of the details of the model, should read Chapters One and Five first, and then turn to the introduction of Chapter Two if further detail is desired. Those who are interested in using the model as a foundation for further research should focus their attention on Chapters Two and Three. Finally, individuals who are interested in applying the model as a policy analysis tool should concentrate on Chapters Two through Four. Individuals in the last two categories who are unfamiliar with the symbology of system dynamics should scan Appendix A prior to reading Chapter Two.

The authors hope this guide saves the reader time in gaining the degree of understanding desired.

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CHAPTER 1

INTRODUCTION

Department of Defense (DoD) systems acquisition policy guides DoD acquisition from analysis of mission area needs through the production and deployment of selected systems. Acquisition system effectiveness is largely determined by how well the implemented policy directs and controls the acquisition process as the process is acted on by internal and external environmental factors. The internal environment encompasses the operation of the acquisition process as developments proceed through the acquisition cycle and as military research, development, test and evaluation (RDT&E) are interfaced with contracted research, development, and production. The internal environment also includes the operation of control and reporting systems, such as the Defense Systems Acquisition Review Council (DSARC) and the Planning Programming and Budgeting System (PPBS). External factors include the perceived threat and reaction to it, economic and technological constraints on the activities of the system, and requirements and controls set forth by the President and the Congress. The relationships and interactions between the environment and the acquisition process define the acquisition system. Understanding the structure of these relationships and

interactions, and developing an appropriate policy are necessary if the policy maker is to effectively control the acquisition process.

In the past two decades three major policy revisions have been introduced. In the 1960s, Secretary of Defense McNamara introduced a new organizational structure to centralize the decision making process (14:3). Included in the structure was the PPBS and a strong systems analysis group within the DoD (14:94). In 1971 Secretary Packard introduced ten major policy elements to begin decentralization of responsibility and authority for acquisition management, and to reform the acquisition process (7:2). Secretary Packard established the DSARC and directed publication of DoD Directive 5000.1 to codify the DSARC system and acquisition guidelines (7:2). The 1981 Acquisition Improvement Initiatives, directed by Deputy Secretary of Defense Carlucci, provide for "controlled decentralization [3:1]" of program management decisions, closer ties between DSARC and PPBS, and reduction of acquisition cost and time through a number of initiatives including Multiyear Procurement, and Preplanned Product Improvement (3). DoD policies provide guidance, in the aggregate, for acquisition system operation and the decision structure to be used by acquisition managers, (from the Defense Acquisition Executive to individual element managers), in managing acquisition programs. Each policy revision changed much of the existing policy to

more effectively control the acquisition system under the conditions then existing. The frequent major changes in acquisition policy highlight a continuing need for policy makers to be able to study the effects of a policy change before implementation, and to study the effects of a changing environment on the acquisition system.

The tools previously available to the policy maker were judgment, intuition, experience, and analytical analysis of segments of the acquisition system. However, the acquisition system is large and complex, with many interrelationships existing between components of the system that are difficult for the policy maker to visualize and understand. In addition to direct relationships, a complex information feedback system has been created which provides second and higher order feedback effects throughout the acquisition system. Forrester (10:Chp.1) described how managers and policy makers in complex systems can benefit from the development of dynamic models, from both the information obtained and the understanding gained of the system by development and operation of a policy model. A dynamic policy model of the acquisition system would provide policy makers with a tool to use in addition to their intuition, judgment, and experience in managing the acquisition system.

Problem Statement

A completed policy model of the DoD acquisition

system did not exist prior to the implementation of the three major policy initiatives. A dynamic policy model incorporating system structure and decision rules will enable DoD policy makers to study the effects of policy changes and the environment on the system over time. A policy model would also provide a vehicle for policy makers to use in understanding the dynamic nature of the acquisition process.

Research Question

What is the structure of the acquisition system and decision policies, how can the structure be captured in a dynamic model, and how can the model be used to evaluate specific policies? Specifically:

1. What are the significant relationships in the DoD acquisition system that can be used to model the decision and structural aspects of the acquisition system at the policy level?

2. How can these relationships be incorporated into a model that will enable DoD policy makers to evaluate the system and policy alternatives?

Objectives

The primary objective of this research was to provide a validated broad-based structure in which specific policies could be more fully developed and evaluated. Intermediate objectives were:

1. Develop a policy model of the DoD acquisition system and its environment.

2. Verify and validate the model.

3. Use the model to evaluate a specific policy area and provide guidance on how to use and alter the model for policy analysis.

Scope

This research was directed at understanding and modeling acquisition policy within DoD. The acquisition model presented here was developed at a high level of aggregation and primarily is intended to portray the strategic policy structure of the DoD acquisition system. Lower levels of aggregation were used only where the detail involved was required to capture a major concept. The model parameters and outputs were designed to show what trends would be associated with implementation of a policy.

Emphasis was placed on the dynamic relationships within the acquisition system and how they are affected by policy and external pressures. Exogenous factors input to the model include broad representations of US and Soviet economic conditions. The Soviet threat is generated in the model as a response to the threat perceived by them, subject to economic and political constraints.

Background

Five previous efforts at modeling all or part of the DoD acquisition system were done by Elder and Nixon (8), Lawson and Osterhus (20), Kaffenberger and Martin (19), Sweeney (29), and Brechtel (2). Each of these studies contributed conceptual ideas that were incorporated in and

provided a framework for future research. Brief discussions of the contributions of these five studies are presented below.

Elder and Nixon. Elder and Nixon (8) developed a conceptual model of the Aeronautical Systems Division of Air Force Systems Command. While Elder and Nixon did not produce a completed model, they were able to complete one sector of the model--the process of project management. Elder and Nixon provided a conceptual base for viewing program management, which Kaffenberger and Martin later used.

Lawson and Osterhus. Lawson and Osterhus (20) applied the system dynamics methodology to the DoD acquisition process and developed the six sector model depicted in Figure 1.1. Lawson and Osterhus provided an easily understood, intuitive, set of causal relationships describing the DoD acquisition process from the macro perspective. The structure developed by Lawson and Osterhus provided the first step towards a comprehensive model of the policy level DoD acquisition model.

Kaffenberger and Martin. Kaffenberger and Martin (19) built upon Elder and Nixon and Lawson and Osterhus' research to develop a detailed model of the acquisition process. The Kaffenberger and Martin model (Figure 1.2) contained ten sectors connected by flows of information,

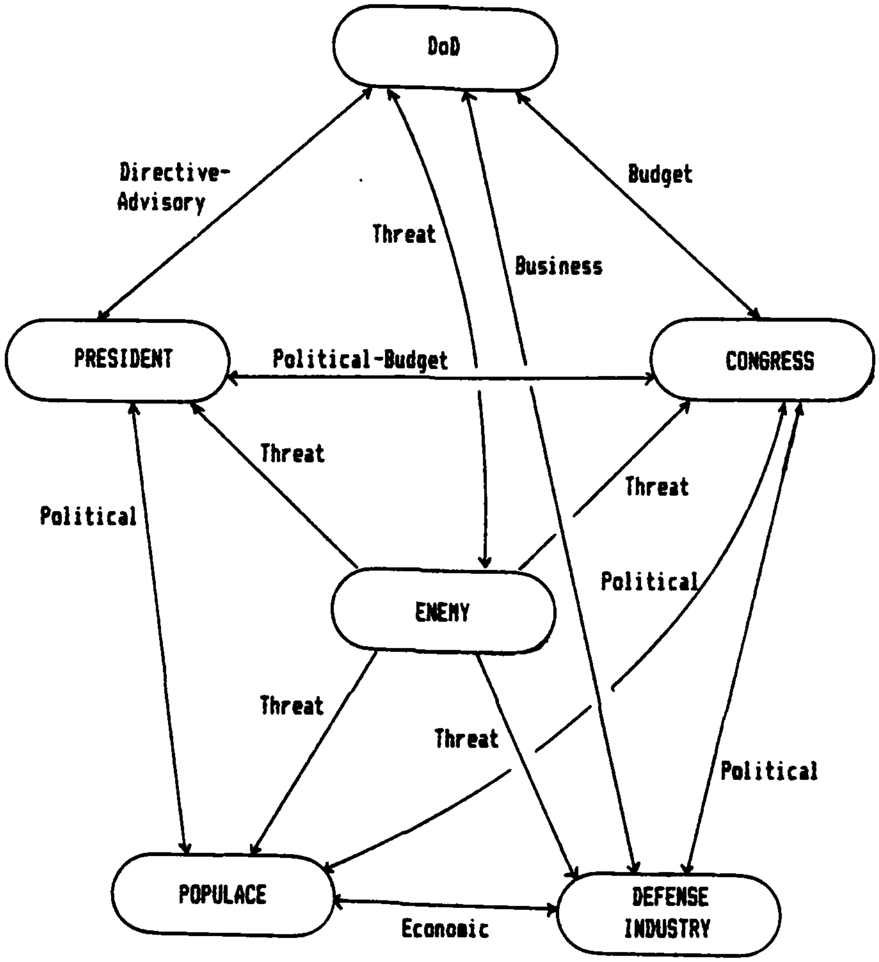

Figure 1.1 Sector Interaction Diagram
(20:Fig.9)

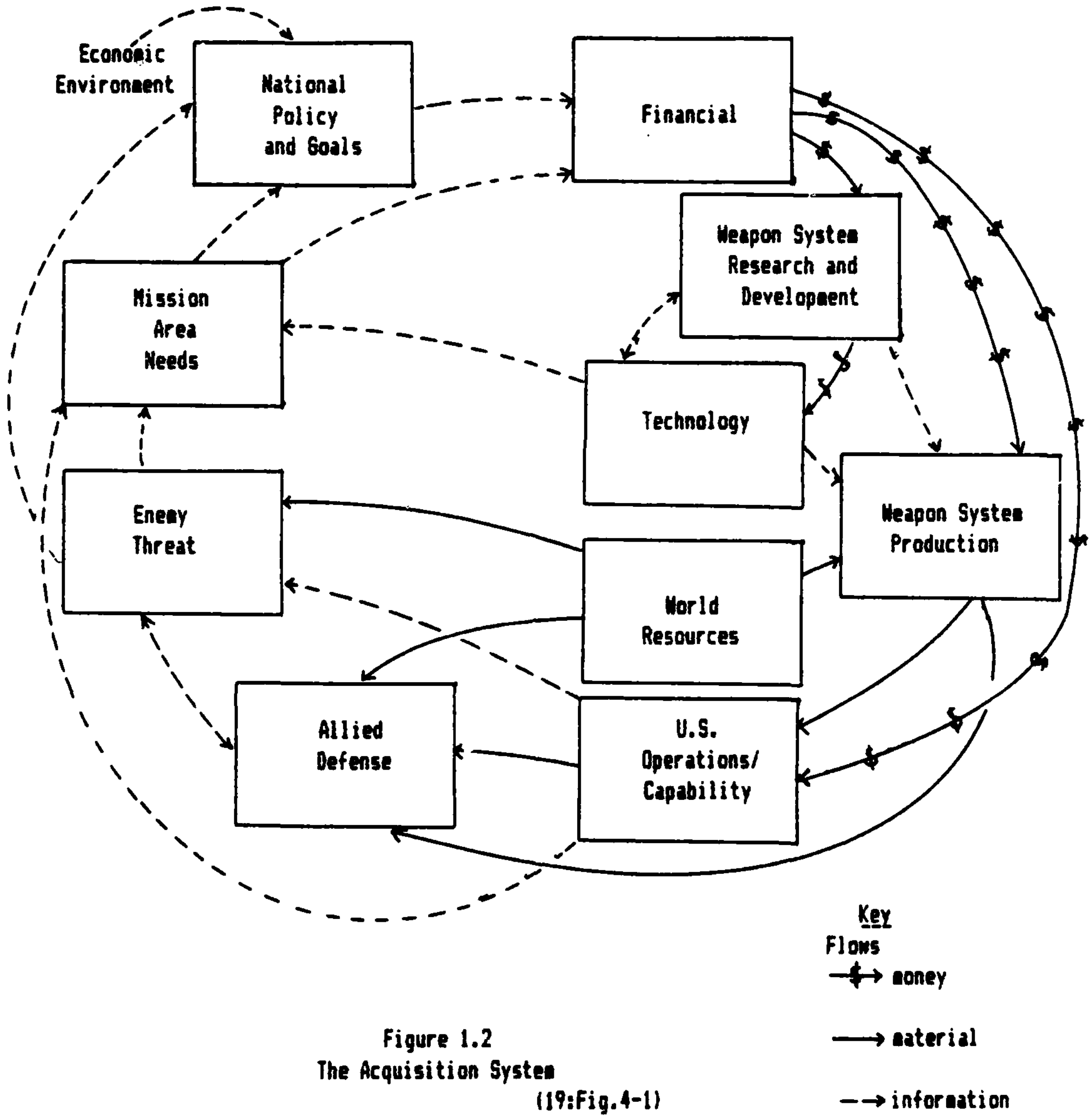

Figure 1.2
The Acquisition System
(19:Fig.4-1)

money, and material. The Kaffenberger and Martin model is almost completely self contained. Much of the environment is modeled to the same level of detail as the acquisition process itself, including all of the necessary feedback mechanisms to model not only the impact of the environment on the acquisition process, but also the impact of the acquisition process on the environment. In addition, the resulting impacts on the acquisition process of these self induced environmental changes were demonstrated by Kaffenberger and Martin. For instance, an increase in the perceived threat results in an increase in the US weapons production, which, in turn, results in an increase in the threat perceived by the enemy. This increase in perceived threat by the enemy results in a further increase in the enemy weapons production, which results in another increase in the threat perceived by the US (19:Fig.4-1). With the addition of constraints imposed by the world resources sector of the model, this feedback loop is a very good representation of the "arms race." Much of this model went beyond the macro level and attempted to model micro level interactions within the acquisition system. Kaffenberger and Martin developed and programmed a dynamic model, but were unable to run or complete validation of the model due to the time constraints imposed upon the research.

Kaffenberger and Martin provided an excellent literature review (19:Ch.2) and description of the acquisition

system (19:Ch.4). The initial approach in this research was to simplify and attempt to validate Kaffenberger and Martin's model. This approach was later abandoned in favor of developing a new model with a more macro level perspective, using Kaffenberger and Martin's research as a valuable source of background material.

Sweeney. Sweeney (29) operated and began validation of six sectors of Kaffenberger and Martin's model. Sweeney's effort was primarily directed at utilizing the model in the Aeronautical Systems Division to enhance procurement management. Sweeney explored decisions involving the rank structure of officers within a program office and the effect of rank structure on the program. Sweeney's evaluation of Kaffenberger and Martin's model was that it was a generally accurate portrayal of the DoD acquisition process (29:3).

Brechtel. Brechtel (2) developed and operated a model of the resource-acquisition process of DoD contractors. The model was first operated to demonstrate that it could replicate the behavior of the actual system over a historical time period for which data were available. The macro-level model was subsequently used to evaluate the impacts of changes in the resource acquisition policy of the contractor. Brechtel's research provided two valuable contributions to this research; (1) a clear and concise

review of the application of dynamic modeling to a development and production organization, and (2) an example of both a completed and clearly documented system dynamics model.

This section has provided background material on five previous studies that worked toward modeling all or portions of the acquisition system using a dynamic modeling methodology. Introduced in the next section is the specific methodology used to develop the dynamic models reviewed.

Methodology

The methodology applied in this research and the research discussed above is that of System Dynamics. The primary factors in this selection were the applicability of system dynamics to large dynamic systems and its usefulness for policy analysis at the macro level of the DoD acquisition system. System dynamics, or Industrial Dynamics as it was first introduced, was developed at the Massachusetts Institute of Technology (M.I.T.) School of Industrial Management by Jay W. Forrester in the late 1950s (10:viii). Applications of the system dynamics approach include a world resources model (12), naval ship production by Litton Industries (5), industrial research and development (28), and a model of the resource-acquisition process of DoD contractors (2).

The System Dynamics Approach. Forrester (10; 11) and Richardson and Pugh (27) have explained the system dynamics

approach to policy analysis and problem solving. This approach isolates those portions of a system, its environment, and information flows within a system that relate to a perceived problem or required policy. Through the use of a mathematical model, researchers analyze the time varying behavior of the interaction between system components and feedback structures. Table 1.1 contains the steps/stages of the system dynamics approach given by Forrester (10:13) and Richardson and Pugh (27:16).

Once the model is developed, it can be modified to reflect changes to the system or environment and used to analyze new problems or proposed changes to the system. Figure 1.3 depicts:

> the iterative nature of the [system dynamics] process ...[and] that final policy recommendations from a system dynamics study come not merely from manipulations with the formal model but also from the additional understandings one gains about the real system by iterations at a number of stages in the modeling process [27:16].

Richardson and Pugh (27:45) and Roberts (28) discuss research and development models that relate the use of resources, project requirements, and project progress. These discussions have provided valuable examples of concepts that apply to the DoD acquisition system, and have contributed to understanding how system dynamics should be applied.

FORRESTER	RICHARDSON-PUGH
1. Identify a problem.	1. Problem identification and definitions.
2. Isolate the factors that interact to create the observed symptoms.	
3. Trace the cause-and-effect information-feedback loops that link decisions to action to resulting information changes and to new decisions.	2. System conceptualization.
4. Formulate decision policies that describe how decisions result from available information streams.	3. Model formulation.
5. Construct a mathematical model of the decision policies, information sources, and interaction of the system components.	
6. Generate system behavior through time with the model.	4. Analysis of model behavior.
7. Compare results to historical data from the actual system.	
8. Revise the model until it is an acceptable representation of the actual system.	5. Model evaluation.
9. Use the model to test modifications to the system.	6. Policy analysis.
10. Alter the real system in directions the model has shown will lead to improved performance.	7. Model use or implementation.

Table 1.1. The System Dynamics Approach

(10:13; 27:16)

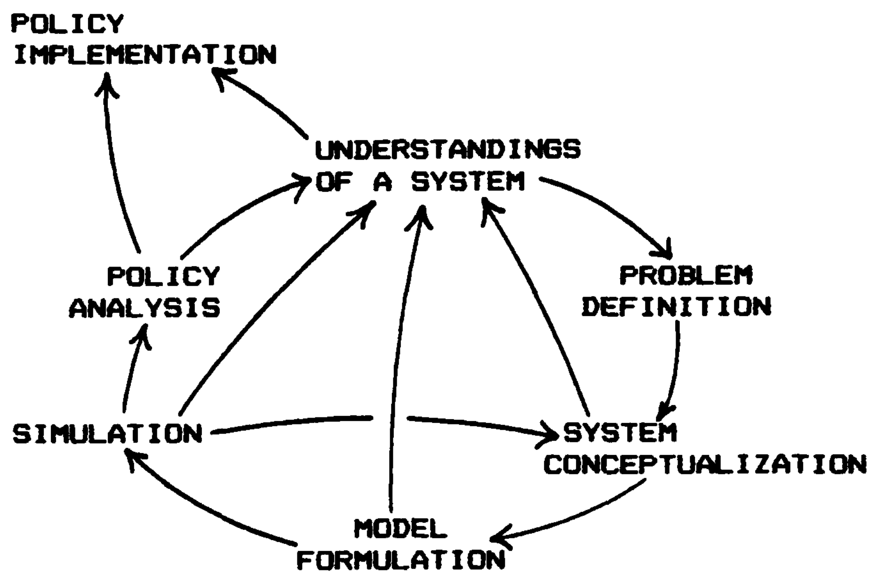

Figure 1.3 Overview of the
System Dynamics Modeling Approach
(27:Fig.1.11)

Applied Methodology. Provided in this section is a general description of how the system dynamics methodology was applied in this research. The iterative process of model building using system dynamics requires recycling through the process described in this section until the model is accepted as accurately representing the system process. The model will continue to be modified and adjusted as policy improvements are tested and implemented. Figure 1.4 provides a general picture of the research sequence. The first step of model construction after problem definition and selection of the methodology is conceptualization.

Initial conceptualization of the system was based on previous studies of the acquisition system and other

Problem Definition | Initial Conceptualization | Model Formulation by Sector | Combine Sectors | Reformulation and Testing

Time →

Initial Literature Research | Initial Interviews | Testing and Validation | Follow-up Interviews | Application

Revise Conceptualization

Figure 1.4 Research Sequence

empirical material. Conceptualization provided a set of causal relationships that were used during the first series of interviews with DoD acquisition participants to verify and correct proposed system relationships. The first series of interviews resulted in increased understanding of the acquisition system and several modifications to the original model as the formulation phase was entered.

The approach used in model formulation was to sectorize the acquisition system into five components that could be modeled and evaluated individually before combining the components to form a model of the entire system. The sectors were defined by grouping related operations and functions from the acquisition system together (for example, grouping budget request and expenditure control in the financial sector). Each sector represented a picture of one segment of the whole that could more readily be modeled and understood than could the entire acquisition system.

Within each sector a flow diagram (see Appendix A for explanation of flow diagrams) was constructed to depict the relationships between the key variables within the sector. The emphasis was put on modeling the first order effects of policy and working with each sector until its behavior and interrelationships matched the observed behavior and structure of the acquisition system. Modeling the first order effects in conjunction with the acquisition system structure enabled the model to reflect the higher order effects of managerial decisions (4). Each sector was computerized and subjected to tests for validation and verification. The computer language used in this research is DYNAMO (10:Appendix A; 11; 25), which was developed specifically for use in system dynamics modeling. The formulation phase accomplished two processes:

> the test of the dynamic hypothesis, which is a preliminary check to see that the basic mechanisms included in the conceptual model actually reproduce the reference mode, and the model improvement, which extends and elaborates upon the initial model until it is sufficiently versatile and detailed to serve the intended purpose [26:130].

The last phase of formulation was to integrate the five sectors into one model of the system. The integrated model was then subjected to numerous tests for verification and and validation (13).

Verification and validation tests took the forms described in Chapter 3. One part of the verification and validation process was the second series of interviews with

acquisition participants. During the interviews, the structure and relationships were evaluated for face validity and data were obtained on parameter ranges and sensitivity to change. The participants' feedback allowed further testing and refinement of the model in preparation for policy analysis. Implementation of the applied methodology is described in subsequent chapters.

Order of Presentation

Discussed in chapters two through five are the implementation of the research methodology, policy evaluation and recommendations for further research.

Described in Chapter Two, The Model, are the DoD acquisition system, the system dynamics model, and how the model reflects the acquisition system. The conceptualization of the acquisition system and the five sectors is presented, followed by a more detailed look at the five sectors used in model construction. The Chapter Two presentation of Conceptual Structure and Research and Development Sector Conceptualization includes an introduction to concepts of system dynamics and major concepts of the acquisition system and the acquisition model.

Outlined in Chapter Three, Testing and Validation, are the tests that were accomplished on the sectors and the integrated model and the behavior of the model.

Discussed in Chapter Four, Policy Experimentation, is the policy analysis that was conducted, alternatives that were evaluated, and findings.

Presented in Chapter Five, Summary, Recommendations, and Conclusions, are the model summary and recommendations for further study.

Summary

Chapter One has presented the problem, research question, and a brief background on previous research and the methodology applied in this research project. Chapter Two presents the model.

CHAPTER 2

THE MODEL

Introduction

This chapter describes the DoD acquisition system, the system dynamics model, model operation, and how the model reflects the acquisition system. The system dynamics model was developed in three phases. First, a conceptual picture of the primary components of the acquisition system was created. Next, the system was divided into five functional sectors that were individually developed and tested. Finally, the sectors were integrated and tested as a single unit. The order of presentation in this chapter follows the phases of development introduced above. The conceptual structure of the acquisition system and model is developed, and the division of the system into sectors is explained. Next, the interaction between sectors will be outlined briefly, followed by detailed discussion of each sector and the sector interactions.

Conceptual Structure

The DoD acquisition system has many components with numerous complex interactions between the components. A key accomplishment in developing the policy model of the system was the identification of the key components and major

interactions within the acquisition system and its environment that determine the impact of DoD policies. The causal diagram in Figure 2.1 depicts the components that were identified through literature research (14; 19; 20; 23; 32) and in interviews as key factors in the acquisition system (see Appendix A for an introduction to causal diagrams). The causal diagram was developed by first identifying the process to be studied, and then identifying the primary forces or elements that impact the operation of the acquisition process. After identification of key elements and relationships, the system was divided into the five sectors shown, which correspond to key processes or development of related elements of information used in the control of the acquisition system. The following paragraphs explain the development of the acquisition system causal diagram and the key concepts used in the development. During the discussion, each sector will be identified and its contributions to others sectors presented.

The first step in developing the system structure was to define a purpose or goal to measure the system accomplishments against, and to provide motivation for acquisition system operation. The goal selected for this model of the acquisition system is to provide the weapon systems necessary for defense of the US and for a deterrent against aggression by enemy forces. This goal and the resulting pressure for accomplishment are embodied in the pressure for

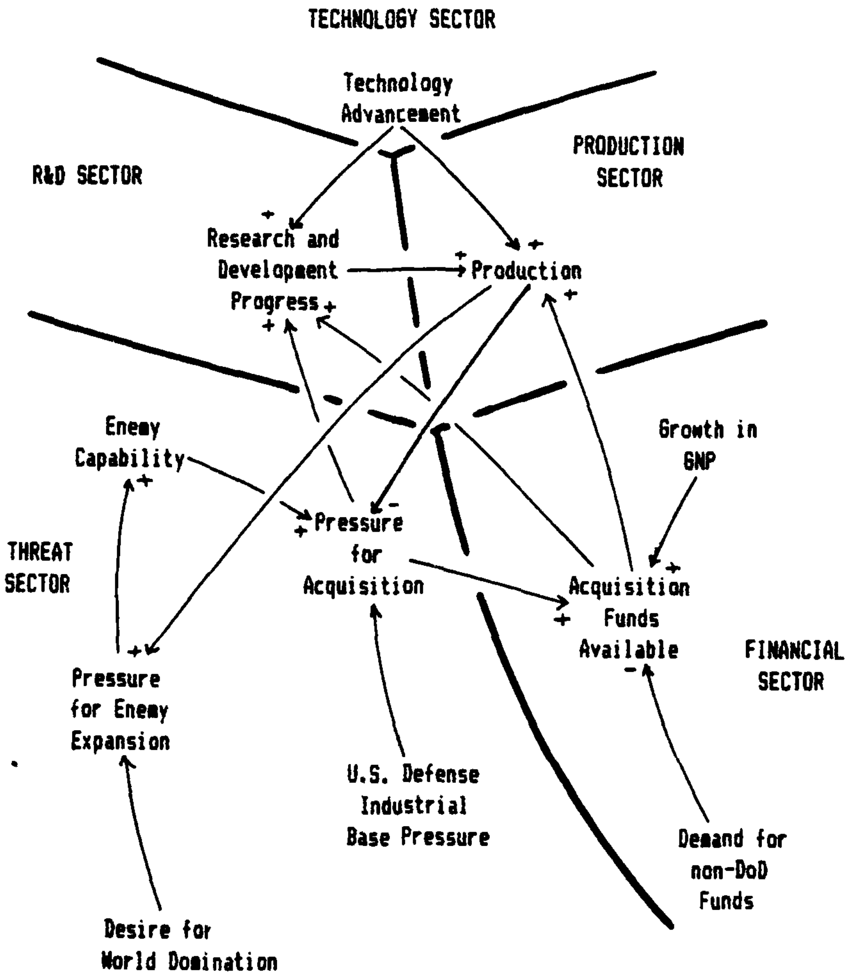

Figure 2.1
Causal Diagram of the
Department of Defense
Acquisition System

acquisition in Figure 2.1. Operationalizing the goal in pressure for acquisition was accomplished by further defining the goal as maintaining parity in the aggregate measure of capability between US and enemy forces. The

Soviet Union was used as the enemy force for comparison of capability in the model, since they are the most frequently cited threat when total force comparisons are made (36:Ch.II).

Capability is a concept that can have many definitions and units of measurement. The definition of a unit of measure for capability was a key element in developing the structure of the model. Examples of available measures of capability include; counting hardware units (airplanes or tanks), personnel in arms, nuclear delivery capability, etc. Requirements for capability measure in the model included applicability to an aggregate measure of a broad range of weapon systems (commonality), (at least across a single mission area), determinability for both the US and enemy forces, and measurability at the aggregate level without micro analysis of specific programs or weapon systems. Other considerations in selection of a measurement unit for capability were requirements to be able to translate resource expenditure into capability, and that the capability units used should be a unit that is used by decision makers when considering the force structure at an aggregate level. The measure selected for capability is the accumulated capital investment in the acquisition and modification of weapon systems. In addition to meeting the requirements and considerations discussed above, the accumulated capital investment is a measure available for both US and Soviet

forces, and is used for relative comparison of capability (1:7; 18:15; 35:2; 36:II-4). Use of this measurement of capability for aggregate force comparison was discussed in the May interviews (see Appendix B) and determined to be an acceptable measure. Relative US and enemy capability is a primary contributor to the pressure for acquisition shown in Figure 2.1 and provides the goal or system objective to drive the acquisition process.

Research and development (R&D) progress and production contain the physical processes and decision structure of the acquisition system. Research and development includes the acquisition process from program initiation to production start. Pressures and resources from the other sectors are used in R&D to control the flow of programs in accordance with policies or decision criteria established by DoD. Although not shown in Figure 2.1 for simplicity, information from R&D is transmitted to the technology and financial sectors containing R&D requirements from the respective sectors, for example, the DoD budget request for R&D to the financial sector. Programs completing R&D enter production.

Production is the creation of capability by either producing new weapon systems or the modification of existing weapons. Programs entering production from research and development result in the creation of new weapon systems and capability. Weapon system modification is included in the

model as an alternative to developing new weapon systems. Without the inclusion of this alternative the boundaries of the system would be inadequate for evaluation of acquisition policies. Progress of R&D programs and the number of R&D programs are increased as the pressure for acquisition increases.

The pressure for acquisition creates major impacts on research and development progress and acquisition funds available. The information provided by pressure for acquisition, and consequently the threat sector, is the need for acquisition of capability, and the urgency of that need. This pressure is developed by comparing long and short term forecasts of relative US and Soviet capability and the requirement to maintain a defense industrial base. Contained within the threat sector is the calculation of enemy capability and enemy response to US acquisition. The enemy's capability grows to meet the threat posed by the US and in response to the enemy desire for world domination. The desire for world domination was identified in several interviews as a base pressure that will maintain enemy force buildup, even when they posses a capability advantage. The pressures created act directly on the acquisition process and indirectly affect it by impacting the amount of resources available for acquisition, as determined in acquisition funds available in the financial sector.

The financial sector provides funds for R&D and

production, and by not providing the full funds requested is also the primary constraint on the arms race that will be discussed later in this section. The acquisition funds available are determined from the budget request submitted by DoD and the pressures applied to the Congress that impact the appropriation of funds. The pressures applied to Congress reflect the political, economic, and threat environments in which the acquisition system exists. Interview discussion confirmed that surrogate measures for the economic and political pressures could be estimated by consideration of the DoD budget request as a fraction of US Gross National Product (GNP), and a demand for non-DoD funds created by the health of the economy. The DoD budget request is determined by the amount of capability that will be needed to meet the enemy threat and an estimate of what acquiring that capability will cost. These calculations and more detailed explanation of them are presented in the discussion of the financial sector later in this chapter. In addition to the threat and resource availability, technology was identified in interviews as a key factor impacting progress and output of the acquisition process.

Technology is a concept that has been defined for the acquisition model as the amount of capability that can be obtained from one production unit (one airplane or one tank). The units for measuring technology are then capability per production unit. For a research and development

program to be completed and advance to production, the technology being used in the program must be developed, tested, and incorporated into a manufacturing design. A standard of how advanced the technology desired for programs in R&D is set and technology advancement or lack of it will then impact the time and cost required for program R&D. Technology advancement impacts production in two ways. First, as technology applied to weapon systems advances, more capability is obtained from each production unit. Secondly, as the technology advances, a need will develop to modify existing forces to maintain the capability to do the job assigned through the weapon system lifetime. As shown in Figure 2.1, the advancement of technology has a positive impact when increased, and a negative impact when reduced, with all other things constant. The causal diagram in Figure 2.1 contains two key feedback loops that are discussed next.

System Feedback Structures. The portion of the causal diagram shown in Figure 2.2 is a positive or growth reinforcing structure that depicts how arms competition would result in a rapid expansion of forces and expenditure for forces if external constraints (outside the loop shown) were not present to restrict this growth. Acting on the structure in Figure 2.2 are constraints imposed by the availability of resources (dollars), which represents the

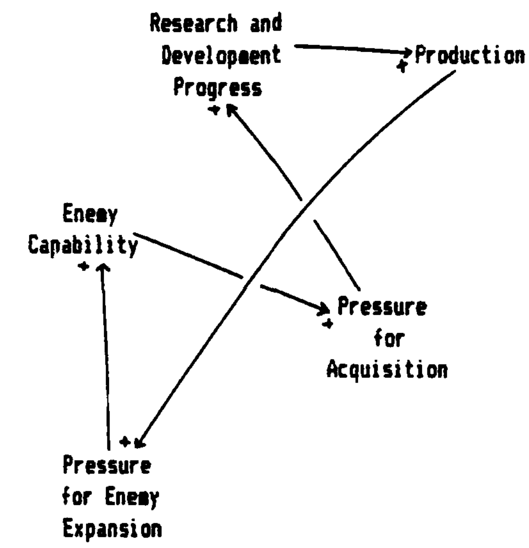

Figure 2.2
The Arms Race

political realities of how much a government can spend on acquisition, and the availablity of technology. The second loop to be discussed is a negative or goal seeking loop.

The goal seeking loop shown in Figure 2.1 by pressure for acquisition, research and development progress, production, and back to pressure for acquisition, represents a smaller and shorter term picture of acquisition in this country that tends to dampen the build up of forces as our forecast of capability begins to compare favorably with the enemy. This points to a possible problem behavior in the system when the comparison being made is with a fairly accurate picture of U.S. force growth, but with a delayed picture of enemy growth that does not adequately reflect the

connection between U.S. production and pressure for enemy expansion. The concepts shown in Figure 2.1 were used as model development entered the formulation phase.

Summary. The output of the acquisition system is the production of capability that provides both a deterrent and active defense. The inputs to the system are pressures that impact allocation of resources or funds available, representing the perceived difference between U.S. and enemy capability, and the current economic conditions. Each of the five sectors are discussed in detail below. Each sector discussion will contain a sector overview describing inputs and outputs of the sector. Following the overview, the sector will be presented by segments, each having a defined function in the sector, and the equations in the segment detailed. The first sector to be discussed is research and development. The R&D Sector Conceptualization will introduce concepts of system dynamics as well as major concepts of the acquisition model.

Research and Development Sector

The research and development sector encompasses the process shown in Figure 2.3, in which pressure for new weapons, resources, and technology, are input and weapon system programs ready for production are output. This discussion of the R&D sector presents an overall view of the

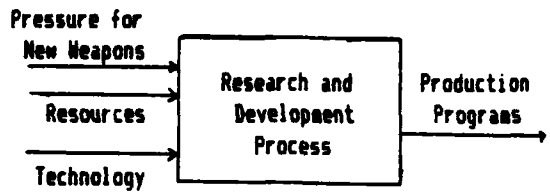

Figure 2.3. The Research and Development Process

process depicted in Figure 2.3, and breaks the sector into three segments. Each segment is then discussed conceptually and the formulation of equations depicting the concepts is presented.

Research and Development Sector Conceptualization. Within the R&D process weapon system development programs are created and progress through three phases of acquisition (31:17-3; 32:4): concept exploration, demonstration and validation, and full-scale development. Hereafter, these phases are called concept, validation, and development phases. The progression of programs through the phases is described conceptually in the model as a flow from one level of processing to the next. Figure 2.4 depicts this flow within the R&D process. Each of the three R&D phases is pictured as a container that holds the programs currently in that phase. Programs enter the R&D process in the concept phase through the valve labeled program new starts and exit R&D as programs approved for production. Program new starts is the rate (number of programs per time period) at which new weapon system programs are initiated and enter the

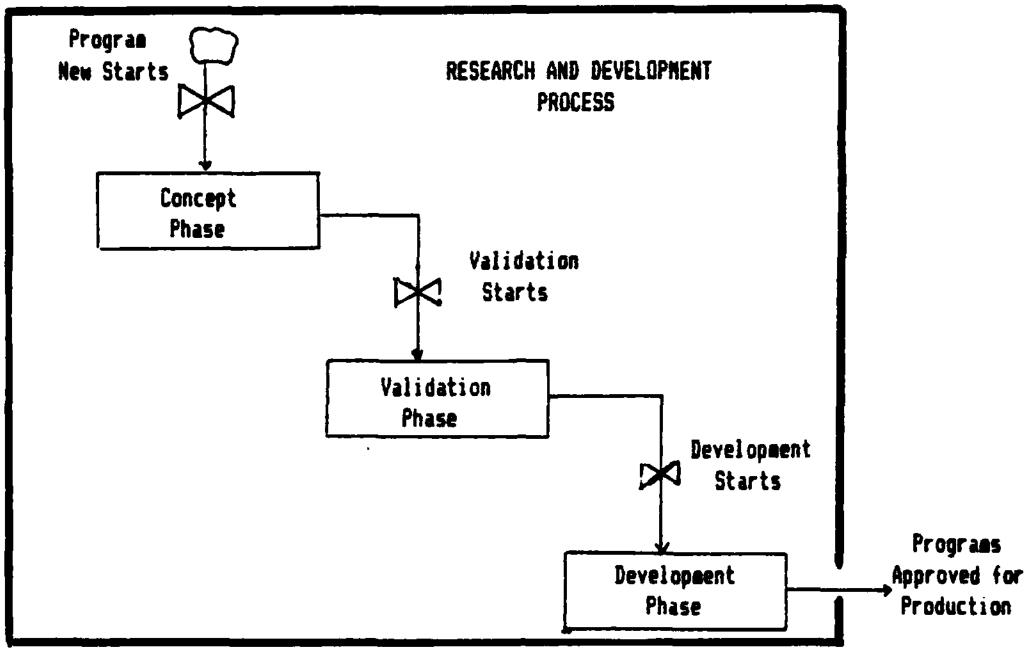

Figure 2.4 Phases of Research and Development

concept phase. A level of programs exists in the concept phase that are having work accomplished before proceeding to validation. In each phase, programs are delayed while the required processes in that phase are accomplished. For example, in the concept phase alternative solutions to the need are developed, evaluated and one or more alternatives selected for further development if program advancement to the next phase is approved. A simplified picture of the R&D process is a series of rates and levels that weapon system development programs flow through. The rates can be pictured as a valve controlled by policies that opens and closes to control the advancement of programs between phases. The levels or phases can be seen as reservoirs of

programs in that phase. This basic structure of research and development will be built upon as more model concepts are presented. The first model concept that must be developed is what a program in the model represents and how programs are measured.

The concept of a program used in the acquisition model considers programs in the aggregate sense as a means of procuring defense capability. For the model, individual programs are not uniquely identifiable, but rather represent an average of the acquisition programs in progress. For example, twenty acquisition programs with resource demands varying between one million and 500 million dollars per year per program, totaling ten billions per year, would be represented in the model by 100 programs, each requiring 100 million dollars per year. Conceptually, the use of an average program allows all programs in the model to be treated equally, and as policies are changed the net effect on the acquisition system studied. The flow of programs within the structure in Figure 2.4 is a continuous process, with programs in all phases of the process. Flow between the R&D phases is controlled by a decision structure defined by DoD policies. Figure 2.5 depicts the decision structure used in modeling the approvals for programs to proceed to the next phase of acquisition.

The rate at which programs progress into the next phase is contingent on two requirements, affordability and

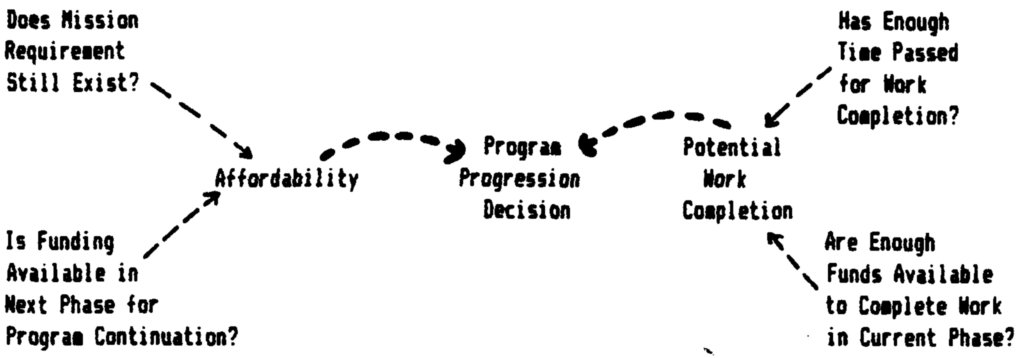

Figure 2.5 Program Progression Decision

work accomplished. Affordability and work accomplishment each provide a maximum rate at which programs may flow into the next phase. Only the number of programs that can be completed in the current phase AND are affordable may progress. The next two paragraphs discuss these concepts.

Work accomplishment is measured through the calculation of an expected time the program would take for completion if the desired level of funding were available, and then adjusted to reflect the actual funding that is available. The expected time for programs to complete each phase is dependent on different relationships for each phase. The conceptual framework for expected time is unique to each phase and will be presented later in this section. If the funds available for research and development do not match the requirements for progression in the expected time, then program schedules are stretched or contracted to make funds required equal the funds available in the short run. These short run program changes reflect the tendency for program

acceleration when more funds become available than were planned for and also the legal requirements that programs not spend more money than authorized. The long term effects of these short run changes to meet funds availability requirements are discussed after introduction of the second limit on program progression, affordability.

The affordability concept combines two key ideas: how much of a need exists for programs (how great is the threat), and the funding availability for the system life cycle as required by the draft of DoDI 5000.2 (33:Encl.2). The requirement for funding availability is modeled by considering the number of programs that are completing or being canceled in the next acquisition phase and adjusting that value to reflect the DoD desired response to the enemy threat; that is, increase programs when a threat exists that is not currently being met or reduce programs if excessive U.S. capability is forecast. The use of the next phase for determination of funding availability was felt to be sufficient under the assumption that if funding was available for the next several years, then funds could be included in the Five Year Defense Plan (FYDP) and Extended Planning Annex (EPA) for the out years. The use of the program flow out of one phase to influence the flow from the previous phase creates a feedback relationship between the phases as shown in Figure 2.6. The feedback is depicted with information flow (dashed lines) from the rates of development program

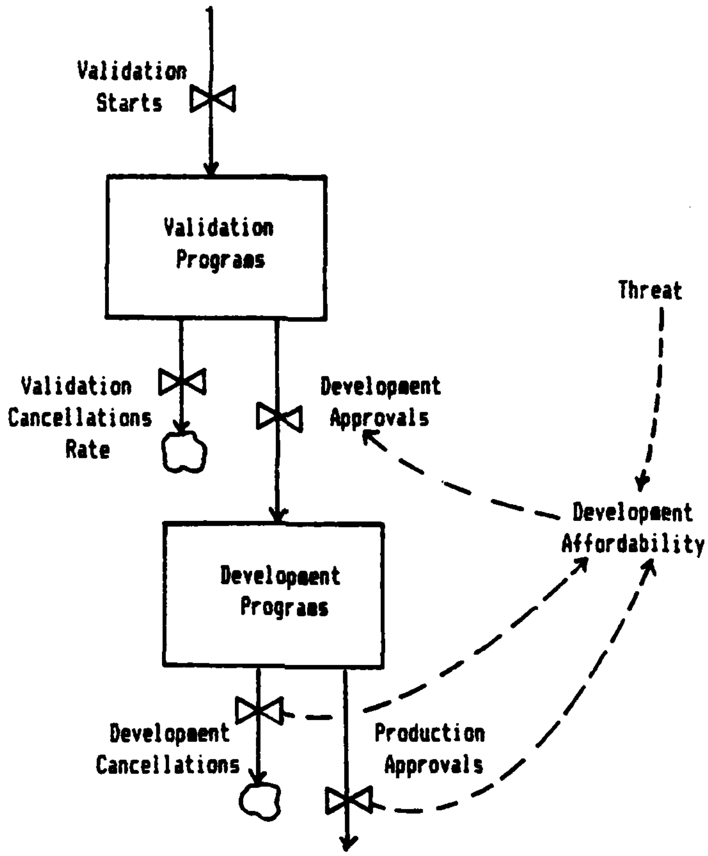

Figure 2.6
Flow Diagram
Depicting Development Affordability

cancellations and production approvals to development affordability and consequently development starts. This feedback relationship creates a structure that is somewhat self regulating in nature and will tend to find an equilibrium flow of development starts when the threat and validation starts remain relatively stable. Excess program affordability does not directly push programs, but does influence the funding requested in the budget and through increases in appropriations, can indirectly push programs. When more

programs can be completed in a phase than are affordable, two alternatives are available. The first is to stretch the programs to a "window" where the programs may become affordable, and the second is to cancel programs. A mix of these two alternatives is employed in the model. In the concept phase, programs are not stretched, but are canceled if more can be completed than are affordable. In validation and development phases programs are initially stretched by reducing the amount of work accomplished and consequently the number of program completions to match the affordable starts for the next phase.

The stretchout of programs for funding constraints and for affordability constraints is an alternative to program cancellations and will eventually result in the cancellation of programs as longer programs become more susceptible to cancellation. The Acquisition Cycle Task Force (6:60-62) found that the probability of a program being canceled increased each year in the life of a program, as shown in Figure 2.7. This reflects that as the acquisition time for a program extends there is "frequently a shift in the perception of priorities,attitudes, and appreciation of the external threat [6:60]," resulting in increased probability of program cancellation. The cancellation rates in validation and development phases are modeled as a function of the average lifetime of programs in that phase using the Defense Science Board study data (6:Fig.11). The

cancellation of programs in the concept phase applies the Defense Science Board study data and adds the cancellation of programs completing concept phase that are in excess of the affordable validation starts. Interview discussions determined that the addition of non-affordable programs to cancellations reflects the current DoD emphasis. This incorporates the concept of canceling non-affordable programs early in the life cycle before large expenditures are made. The interpretation of the Defense Science Board data as applied here was verified by interview with the Executive Secretary of the task force (30). In addition to increasing the probability of cancellation when programs are stretched, the total cost for the programs will be changed.

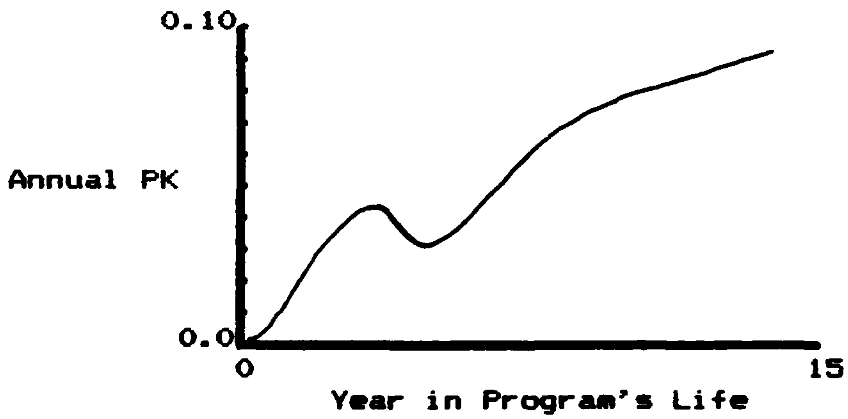

Figure 2.7 Program Survival Function (Probability of Program Cancellation)
(6:Fig 11)

Interview discussions about the effect on program cost of changing program schedules or deviating from the planned rate of progress on a program confirmed that these changes will usually result in a higher total cost for the

program. Peck and Scherer discussed the relationship between time and resources (23:Ch.9) and show on the combined development possibilities curve (see Figure 2.8) that the total resources required for a project will vary as the duration changes. They also show that there is a minimum cost from which cost will increase both with increasing and decreasing time. The discussion presented by Peck and Scherer was primarily directed toward initial project planning, but interview discussions revealed that a similar relationship exists after projects begin and in fact larger cost changes may exist as a result of requirements to change contracts and planned levels of effort after program initiation.

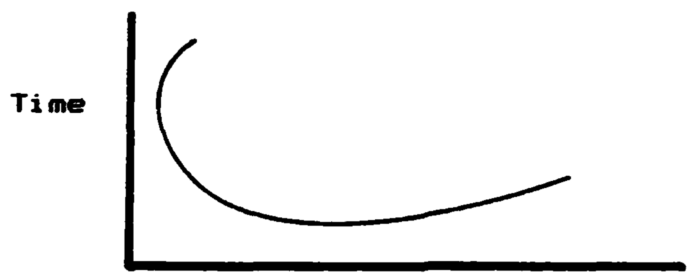

Figure 2.8
Combined Development Possibility Curve
(23:Fig.9.6)

The determination of schedules for R&D programs is a very complex process, in which the unique requirements of each program are incorporated into a schedule of milestones to be accomplished. Program schedule in the model is

defined as a series of program progression decisions that coincide with the acquisition lifecycle milestones I, II, and III, and separate the three phases of research and development. The concept phase is one of study and alternative solution development. It is pictured as a fairly determinable stage which has the pressure of trying to stay on schedule or run a high risk of having the program canceled. As such it is modeled as a constant duration, with an average value for all programs input to the model. As was mentioned before, concept programs are canceled rather than stretched by affordability. Due to its relatively low cost (less than one percent of life cycle cost) the concept phase is treated as getting all the funds required and programs are kept on schedule. This is not true for validation and development phases. In each of these two phases an expected duration is determined in the model that is dynamically adjusted over time by funding and affordability factors. The expected duration of validation is dependent on how much advanced technology is being reached for. Validation is viewed as a risk reduction and analysis phase in which the technology to be used must be tested and, if necessary, discovered before proceeding to development. The technology sector conceptualization defines levels of technology advancement varying from using off the shelf products to developing and integrating entirely new technologies. The validation duration is determined from the expected time

required for the advancement of technology to the required level and is adjusted as technology growth rate changes. More detailed explanation of technology growth is presented in the technology sector. The average development duration is modeled as an input base value that grows over time as the technology being used increases in complexity. This is done with the view that the development process is one that takes technology and initial planning accomplished in the validation phase and outputs a developed program ready for production.

Research and development sector concepts introduced include: the research and development process, the three phases of acquisition, program progression decision, affordability, program cancellations, and phase duration. The application of the concepts developed here will be presented in the formulation discussion on each of the phases. The first phase to be presented is the concept phase.

Concept Phase. New programs are created in the concept phase, are processed, and are either canceled or approved as validation starts (see Figure 2.9). The concept phase discussion presents the formulation of program new starts, concept phase cancellations, validation starts, the determination of the number of programs in the concept phase, and determination of funds expended on concept programs.

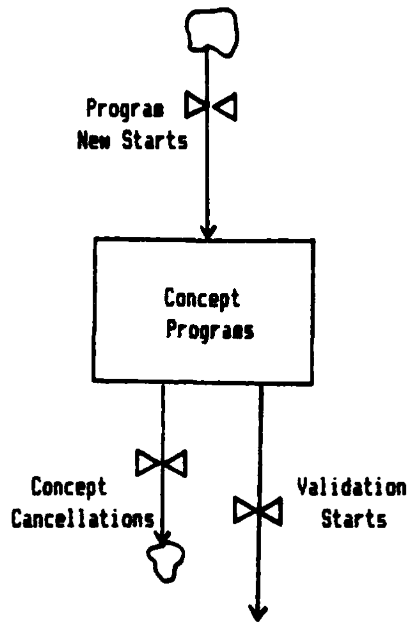

Figure 2.9 Concept Phase Overview

The determination of the rate of new program starts is a surrogate measure for a complex process of mission requirements analysis, resource evaluation, and requirements prioritization that culminates in a new major weapon system start. The relationships shown in Figure 2.10 and equation RD1 were developed from information obtained in interviews and analysis of system behavior. Appendix A provides an explanation of symbols and format used in flow diagrams.

The pressure for research and development provides a measure of the long term threat that must be met with new weapon systems. The pressure for research and development is adjusted to reflect the number of new programs that must be started to meet the threat within the planning horizon.

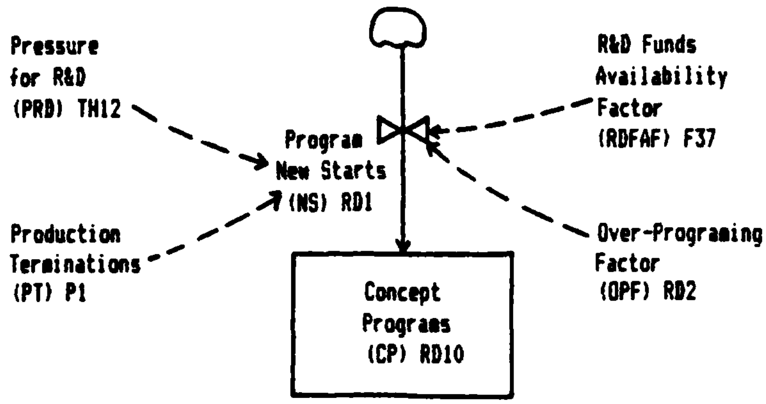

Figure 2.10 Program New Starts Flow Diagram

The research and development funds availability factor provides a pressure reflecting how well the existing programs are being funded. A pressure of one indicates full funding, while a pressure less than one indicates R&D is not receiving all the funds required for advancement at the scheduled rate. The over-programing factor increases the program starts to account for programs that will be cancelled before reaching production. Production terminations provides a base value of programs from which to determine new starts. Use of terminations as a base for starts also reflects a perceived policy of working to maintain the industrial base. The values of production terminations and R&D funds availability factor are exponentially smoothed over twelve months before use in determining new starts. The exponential smoothing causes the determination of new

starts to respond to averaged values of the variables rather than short term fluctuations. Formulation of the rate of new starts is shown in equation RD1.

```
R NS.KL=(1+(PRD.K-1)*2)*SMOOTH(PT.JK,12)*OPF.K
        *SMOOTH(RDFAF,12)                                   RD1
```

OPF = Over-programing Factor (dimensionless)
PRD = Pressure for Research and Development (dimensionless)
NS = Rate of Starting New Program Units (programs per month)
PT = Rate of Production Terminations (programs per month)
RDFAF = R&D Funds Availability Factor (dimensionless)

The required over-programing is determined by summing the fractions of programs being canceled in each acquisition phase. Adding this sum to one creates the multiplicative factor for determining new starts as shown below.

```
A OPF.K=1+CCF.K*CDUR.K+VCF.K*EVDUR.K+
   DCF.K*EDDUR.K                                            RD2
```

CCF = Concept Cancellation Factor (fraction per month)
CDUR = Concept Phase Duration (months)
DCF = Development Cancellation Factor (fraction per month)
EDDUR = Estimated Development Duration (months)
EVDUR = Estimated Validation Duration (months)
OPF = Overprograming Factor (dimensionless)
VCF = Validation Cancellation Factor (fraction per month)

The rate of program cancellations in the concept phase is determined by two conditions, information from the Defense Science Board Study and the program completions in excess of affordable validation starts (see Figure 2.11).

The average age of programs in the concept phase (concept duration) is used with the cancellation table developed from the Defense Science Board data (Figure 2.7) to determine a fraction of the concept programs to cancel each month (the concept cancellation factor). The total concept program cancellations is determined by combining the programs cancelled through the concept cancellation factor and the excess program completions as determined in the clip function. The clip function in equation RD3 compares the affordable starts and program completions, and if the completions are in excess of affordable starts, adds the excess to the program cancellations.

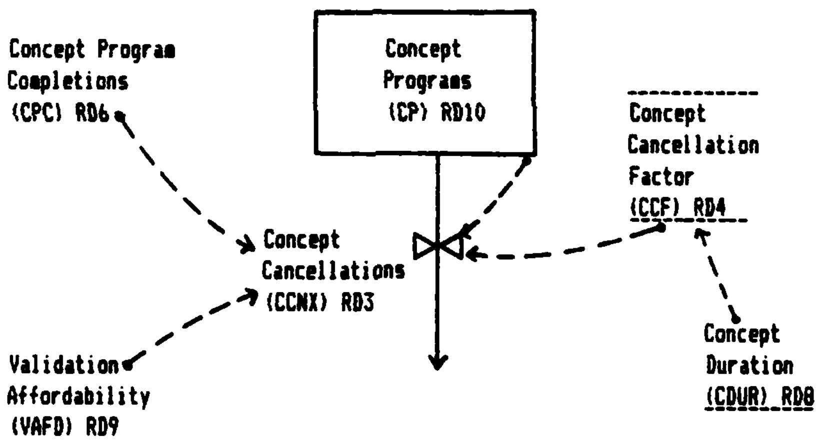

Figure 2.11 Concept Cancellations Flow Diagram

```
R CCNX.JK=CP.K*CCF.K+CLIP(0,CPC.K-VAFD.K,
        VAFD.K,CPC.K)                                  RD3
A CCF.K=TABLE(CNX,CDUR.K,12,180,12)/12                 RD4
T CNX=.003,.025,.035,.046,.033,.036,.052,.065,
        .071,.075,.077,.08,.083,.086,.089,.092,
        .095,.098,.101,.104                            RD5
```

CCF = Concept Phase Cancellation Factor
(fraction of programs per month)

CCNX = Concept Cancellation Rate (programs per month)
CDUR = Concept Duration (months)
CNX = Table of Cancellation Factors
(fraction of programs per year)
CP = Concept Programs (programs)
CPC = Concept Program Completions
(programs per month)
VAFD = Validation Affordability (programs per month)

The rate of validation starts is determined by comparing the programs completing the concept phase and the validation affordability (see Figure 2.12) and selecting the most restrictive of the two as discussed in R&D conceptualization earlier. A measure of the programs completing the

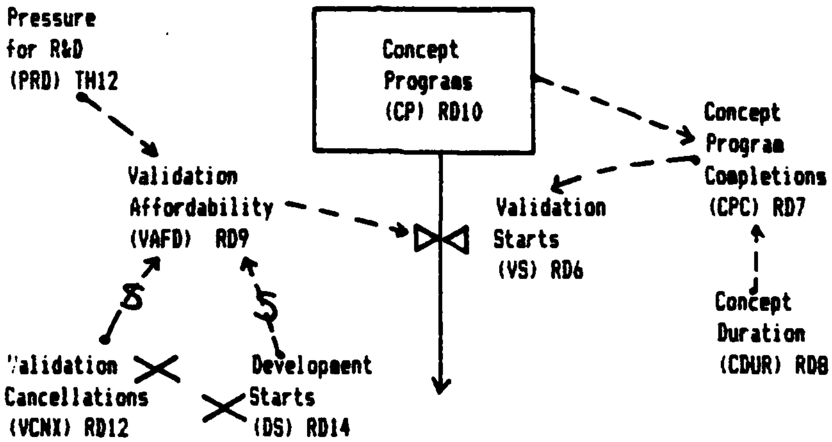

Figure 2.12 Validation Starts Flow Diagram

concept phase is determined by comparing the total number of programs in the phase and the number of months that programs in the concept phase are expected to require (CDUR). It should be noted that the concept duration is a constant value since neither funding shortages or affordability is

allowed to alter the flow of programs through the concept phase. Validation affordability is measured by determining the rate of programs leaving development, cancellations plus production starts, and adjusting the rate for the threat as shown in the pressure for R&D. The information on the rate of programs leaving development is exponentially smoothed so the system will not respond to temporary surges, but rather the longer term trends.

```
R VS.KL=MIN(VAFD.K,CPC.K)                                RD6
A CPC.K=CP.K/CDUR                                        RD7
C CDUR=12                                                RD8
A VAFD.K=PRD.K*SMOOTH(VCNX.JK+DS.JK,12)                  RD9
```

CDUR = Concept Duration (months)
CP = Concept Programs (programs)
CPC = Concept Program Completions
(programs per month)
PRD = Pressure for Research and Development
(dimensionless)
DS = Rate of Development Starts
(programs per month)
VS = Rate of Validation Starts (programs per month)
VCNX = Validation Cancellation Rate
(programs per month)
VAFD = Validation Affordability
(programs per month)

The number of programs in the concept phase is a function of the previous level and the inflow and outflow of programs.

```
L CP.K=CP.J+DT*(NS.JK-(CCNX.JK+VS.JK))                   RD10
```

CCNX = Concept Cancellation Rate (programs per month)
CP = Concept Programs (programs)
NS = Rate of New Starts (programs per month)
VS = Rate of Validation Starts (programs per month)

Costs incurred in the concept phase are determined by the number of programs in the concept phase and a base cost per program per month that is adjusted for inflation (see Figure 2.13). The expenditures made for concept programs each time period is calculated in the financial sector (equation F36), using program and cost information from the R&D sector.

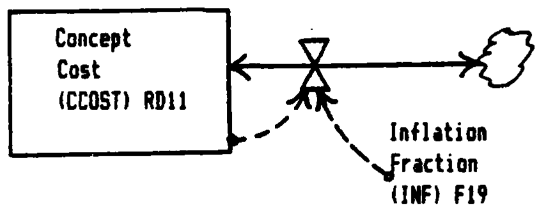

Figure 2.13 Concept Cost Flow Diagram

L CCOST.K=CCOST.J+DT*(INF.J*CCOST.J) RD11

CCOST = Concept Cost ($ per program per month)
INF = Inflation Fraction (fraction per month)

The concept phase has been defined and formulation of concept phase equations discussed. Key concepts in this phase are the determination of new starts, cancellation of programs not affordable in validation, and the flow of programs from concept into validation phase. The validation phase is similar to the concept phase.

Validation Phase. A key difference between the validation and concept phases is the complex determination of potential validation completion rate vs the simplistic calculation of concept completions in equation RD7 above.

This conceptual difference will be discussed and incorporated in the formulation of potential validation completions (equations RD14-24). The basic structure of validation matches the concept phase, with one rate (validation starts) into the level of programs and cancellations and development approvals flowing out (see Figure 2.14).

Figure 2.14 also portrays the determination of validation cancellations. For the validation phase, cancellations are determined from the average age of programs in validation and the table (equation RD5) of cancellations developed from the Defense Science Board data as discussed in R&D conceptualization earlier.

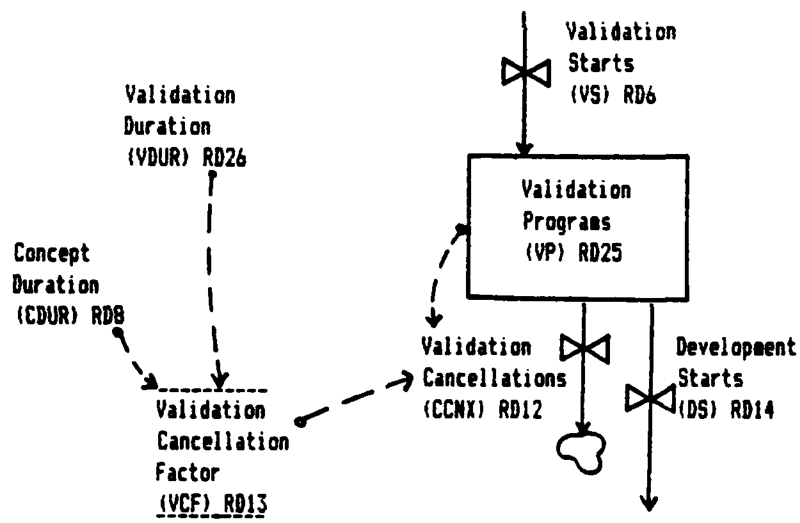

Figure 2.14 Validation Cancellations Flow Diagram

```
R VCNX.KL=VP.K*VCF.K                               RD12
A VCF.K=TABLE(CNX,CDUR.K+VDUR.K),12,240,12)/12     RD13
```

CDUR = Concept Duration (months)

CNX = Table of Cancellation Factors
(fraction per year)
VCF = Validation Cancellation Factor
(fraction per month)
VCNX= Validation Cancellation Rate
(programs per month)
VDUR = Validation Duration (months)
VP = Validation Programs (programs)

The rate of development starts is determined by comparing the development affordability to the potential validation completions (see Figure 2.15) and selecting the most restrictive of the two. Potential validation completions measures the work accomplished and programs ready for progression into development if they are affordable. Development affordability is determined from the exponentially smoothed rate of programs leaving development and the pressure for R&D.

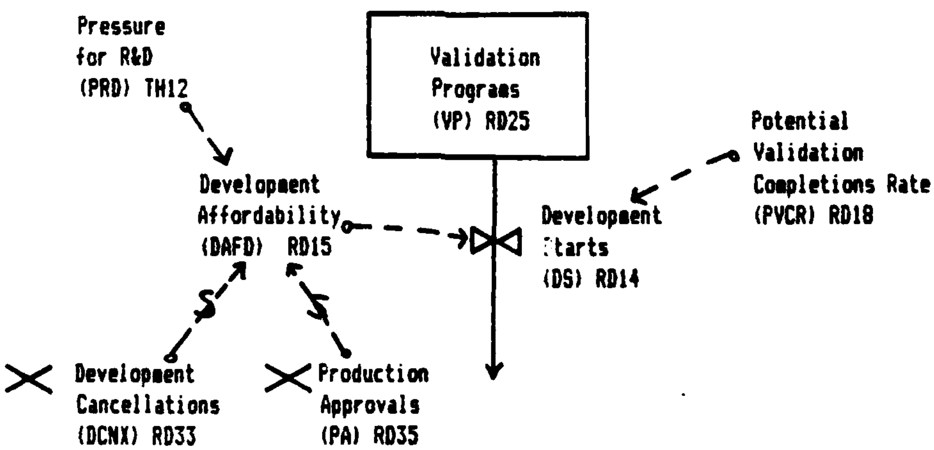

Figure 2.15 Development Starts Flow Diagram

```
A DS.KL=MIN(DAFD.K,PVCR.K)                              RD14
A DAFD.K=PRD.K*SMOOTH(DCNX.JK+PA.JK,12)                 RD15
```

DAFD = Development Affordability (programs per month)
DCNX = Development Cancellation Rate
(programs per month)
PRD = Pressure for Research and Development
(dimensionless)
PA = Production Approvals (programs per month)
PVCR = Potential Validation Completion Rate
(programs per month)
DS = Development Starts (programs per month)

The determination of potential validation completions (Figure 2.16) consists of the expected validation completion rate adjusted for the funds available for R&D progress. Computation of the expected validation completion rate (equation RD16) is accomplished by dividing the number of programs in validation by the expected duration of a validation program. The expected validation duration is determined as a <u>delay</u> of the time required for the technology required for the program to be developed. The formulation of the time required for technology development is contained in the technology sector discussion later in this chapter. The <u>delay</u> between determination of the time required and the implementation of that time for planning as the expected validation duration represents the time between a change in the actual rate of technology advancement and the time at which the manager recognizes the change and implements an adjustment to the schedule.

```
A EVCR.K=VP.K/EVDUR.K                         RD16
A EVDUR.K=DLINF3(TRDTG.K,12)                  RD17
```

EVCR = Expected Validation Completion Rate
(programs per month)
EVDUR = Expected Validation Duration (months)

TRDTG = Time Required for Desired Technology Growth (months)

VP = Validation Programs (programs)

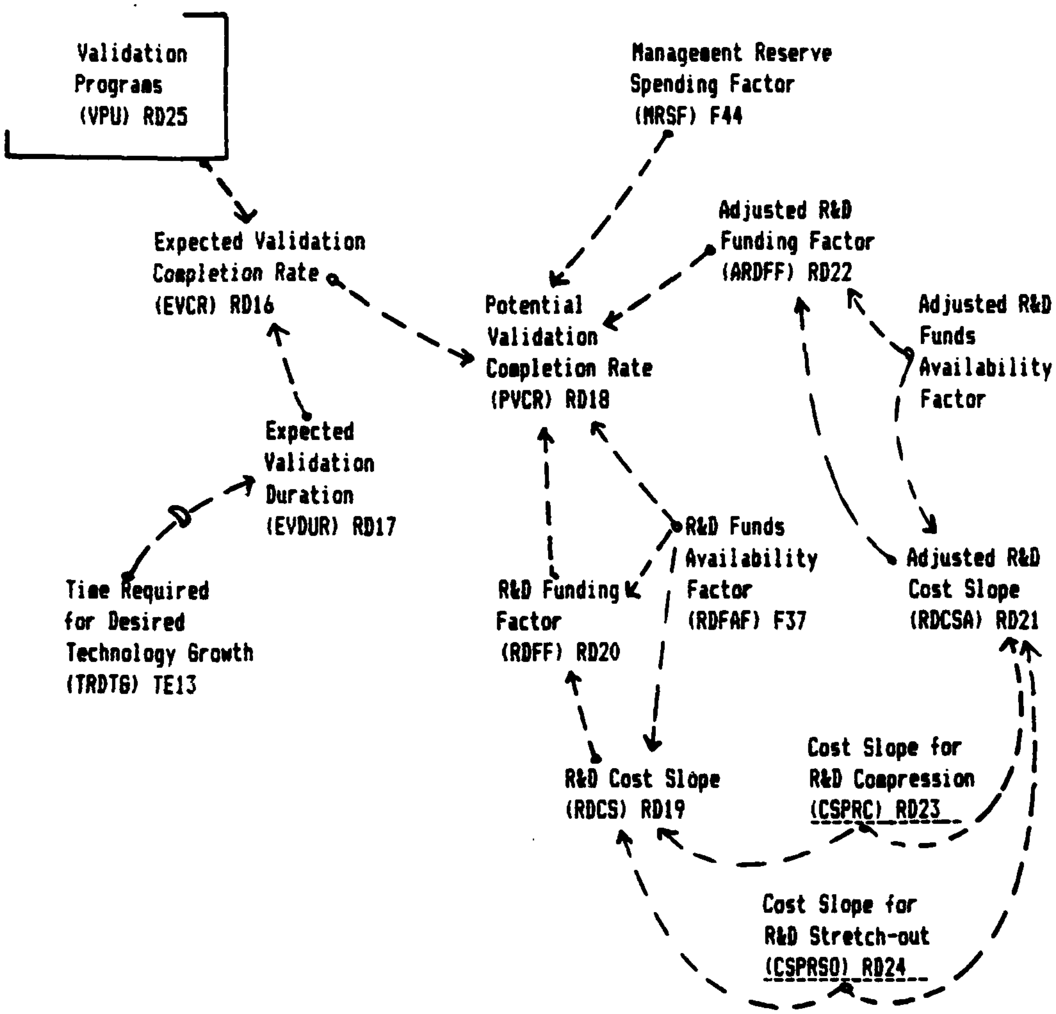

Figure 2.16
Potential Validation Completions
Flow Diagram

The expected validation completion rate is adjusted for funding availability, the amount of work that can be accomplished with the funds available, to find the potential validation completion rate. Funding constraints in the

model are handled by stretching the program. This reflects either a managers conscious slowing of the entire effort to stay within funding limitations, or the deferment of some work until later in the program, which ends up stretching the program unless extra funds can be scheduled for that later time period. If extra funds are available for a program they will be spent, and the program accelerated to some degree. The availability is then tied to schedule changes in programs. In the R&D conceptual discussion above the concept that as schedule changes are made the total cost of the program will change, most probably increase. From discussions during interviews it was determined that a reasonable representation of this changing cost could be made by the diagram in Figure 2.17. The point one-one shows

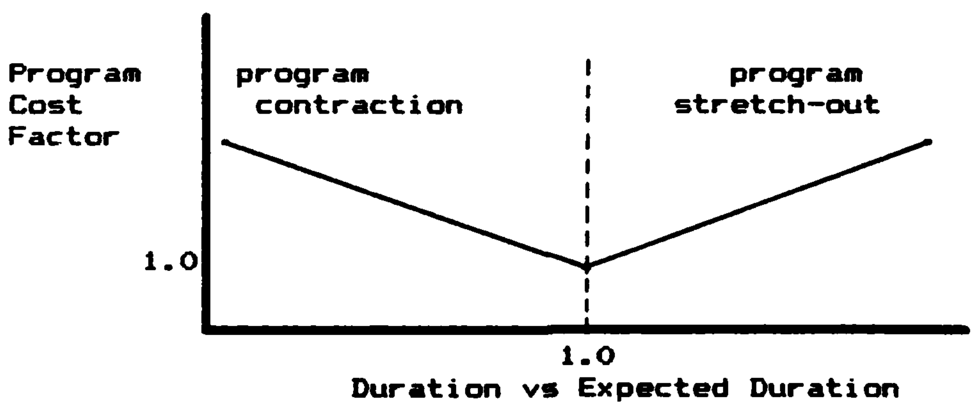

Figure 2.17 Research and Development
Duration Change vs Cost Change

the cost factor equal one when program duration equals expected or scheduled duration. The cost factor is a multiplier on the total program cost reflecting cost of changes

schedule. Values for the two slopes portrayed, CSPRC for program contraction, and CSPRSO for program stretch-out were not available, so assumed slopes of -.5 and .5 were used. These values can be altered by changing the initial assignment for CSPRC and CSPRSO. The calculation of work accomplished with the funds available uses a R&D funds availability factor determined in the financial sector by comparing funds required for progression in the expected duration to the funds available. Equations RD18 through RD24 use the duration change vs cost change relationship shown in Figure 2.17 to translate the R&D funds availability factor and the expected validation completion rate into potential validation completions (see Figure 2.16). Explanation of equations RD18-24 follows the equations and variable definitions.

```
A PVCR.K=EVCR.K/MAX(RDFF.K,CLIP(ARDFF.K,1,
       RDFAF.K,MRSF.K))                            RD18
A RDCS.K=CLIP(CSPRC,CSPRSO,RDFAF.K,1)              RD19
A RDFF.K=((1/RDCS.K)-1)/((RDFAF.K/RDCS.K)-1)       RD20
A RDCSA.K=CLIP(CSPRC,CSPRSO,ARDFAF.K,1)            RD21
A ARDFF.K=((1/RDCSA.K)-1)/((ARDFAF.K/RDCSA.K)-1)RD22
C CSPRC=-.5                                        RD23
C CSPRSO=.5                                        RD24
```

ARDFAF = RDFAF Adjusted to Include Management Reserve
((available-reserve)/required)
(dimensionless)

ARDFF = RDFF Adjusted to include Management Reserve
(dimensionless)

CSPRC = Cost slope for R&D Program Contraction
(dimensionless)

CSPRSO= Cost Slope for R&D Program Stretch-out
(dimensionless)

EVCR = Expected Validation Completion Rate
(programs per month)

MRSF = Management Reserve Spending Factor (dimensionless)
PVCR = Potential Validation Completion Rate (programs per month)
RDCS = R&D cost Slope for adjusting for funds available (dimensionless)
RDCSA = R&D cost slope for adjusting for funds available with management reserve included (dimensionless)
RDFAF = R&D Funds Available Factor (available/required) (dimensionless)
RDFF = R&D Funds Correction Factor (dimensionless)

In equation RD18 the potential validation completion rate is determined by adjusting the expected validation completions for the funds available. A key to understanding the decision structure in the denominator is the use of a management reserve in the model. The management reserve is modeled as a percent of requested or required funds, that is to be maintained until the last three months of the year, when the management reserve is available for use. The denominator of equation RD18 tests for three conditions that can exist and selects the appropriate adjustment factor as outlined in table 2.1. The management reserve spending factor is an indicator of how much reserve is required and in keeping with the reserve policy just described is equal to the desired management reserve factor for the first nine months of the year and 1.0 for the last three months to allow expenditure of any reserve remaining. Equations RD20 and RD22 determine work rate adjustment factors without a management reserve included (RDFF), and with a management reserve (ARDFF). Equations RD19 and RD21 determine if a

Condition	Response
Funds required > Funds Available (without reserve)	Reduce rate of work accomplishment to match funds available and IAW the relationship in Figure 2.17
Funds required < Funds available (without reserve) and Funds required (with reserve) > Funds Available	Proceed with desired rate of work accomplishment
Funds required < Funds available (with reserve)	Accelerate work accomplishment to use the funds available in excess of required reserves

Table 2.1 Funds Conditions and Model Response

contraction or stretchout condition exists (funds available are greater than or less than the funds required) and assign the proper slope for use in equations RD20 and RD22. The funds required and funds available used in the calculation just described, incorporate all activities in the research and development sector in a single funds availability factor used both in validation and development calculations. The calculations in RD19 through RD22 are used for both validation and development phases under the assumption that funds shortages or overages would, at the aggregate level, be felt equally in validation and development.

The level of programs in validation is determined from the previous level and the flow of programs in and out of the level. The duration of the validation phase is calculated by comparing the number of programs currently in validation to the rate of development starts.

```
L VP.K=VP.J+DT*(VS.JK-(DS.JK+VCNX.JK))            RD25
A VDUR.K=VP.K/DS.JK                               RD26
```

DS = Development Starts (programs per month)
VS = Validation Starts (programs per month)
VCNX = Validation Cancellation Rate
(programs per month)
VDUR = Validation Duration (months)
VP = Validation Programs (programs)

The monthly expenditure per validation program is determined from a base cost adjusted for inflation, weapon system complexity, and for the additional cost incurred when the desired validation duration differs from the current duration (Figure 2.18). The weapon system complexity factor

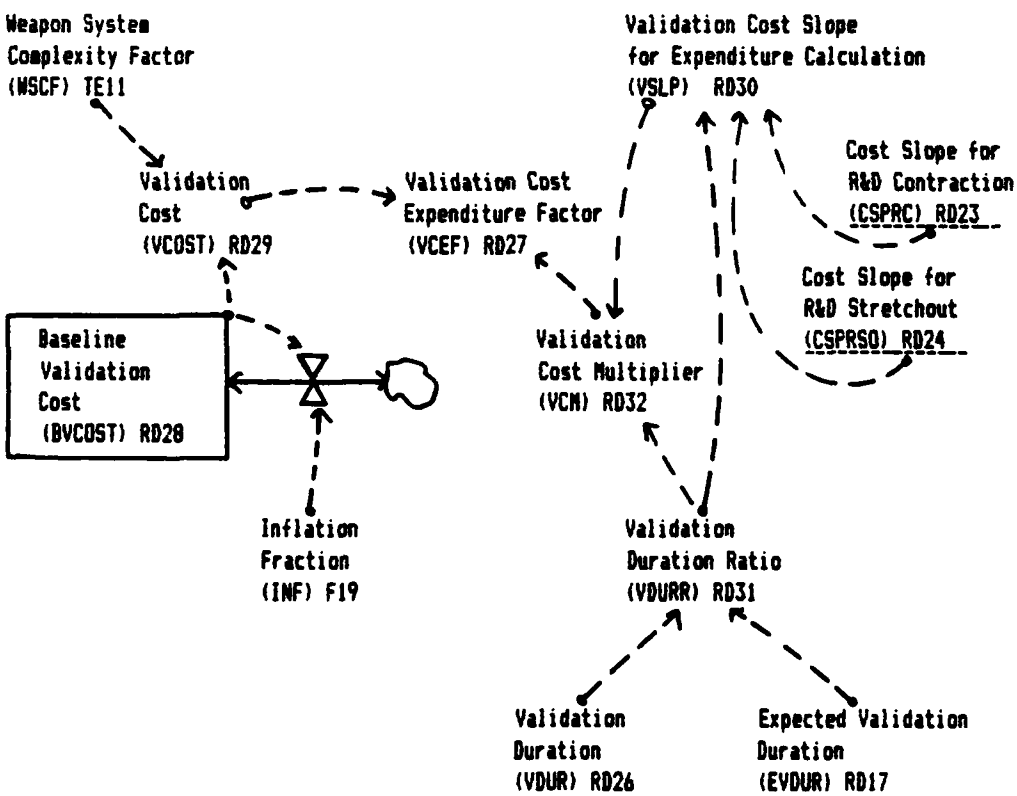

Figure 2.18 Validation Costing Flow Diagram

is determined in the technology sector (equation TE11) and is used here to show a long term increase in validation cost as a result of the increasing complexity of weapon systems and the testing of weapon systems as technology advances. Variations from desired schedule caused by affordability or funding constraints are accommodated by computing the ratio of actual vs expected duration (VDURR), computing a cost adjustment factor (VCM) from VDURR and the cost-duration relationship in Figure 2.17.

```
A VCEF.K=VCM.K*VCOST.K                                  RD27
L BVCOST.K=BVCOST.J+DT*(BVCOST.J*INF.J)                 RD28
A VCOST.K=BVCOST.K*WSCF.K                               RD29
A VSLP.K=CLIP(CSPRSO,CSPRC,VDURR.K,1)                   RD30
A VDURR.K=VDUR.K/EVDUR.K                                RD31
A VCM.K=((VDURR..K-1)*VSLP.K+1)/VDURR.K                 RD32
```

BVCOST = Baseline Validation Cost
($ per month per program)
CSPRC = Cost Slope for Program Contraction
(dimensionless)
CSPRSO = Cost Slope for Program Stretch-out
(dimensionless)
EVDUR = Expected Validation Duration (months)
INF = Inflation Factor (fraction per month)
VCEF = Validation Cost Expenditure Factor
($ per month per program)
VCM = Validation Cost Multiplier (dimensionless)
VCOST = Validation Cost ($ per month per program)
VDUR = Validation Duration (months)
VDURR = Validation Duration Ratio (dimensionless)
VSLP = Validation Slope for Cost Adjustment
(dimensionless)
WSCF = Weapon System Complexity Factor
(dimensionless)

The validation phase has been defined and the formulation of validation phase equations discussed. Key concepts of the validation phase include determination of

validation duration from the desired technology advancement, and schedule adjustments for funds availability. The development phase will be discussed next.

Development Phase. The development phase is similar to validation, with two exceptions. First, the expected duration of development is not dependent on the push for technology, but rather is defined by a base value (initialized) that is adjusted to reflect more time required for development as the technology being applied increases. This factor reflects the increased complexity of translating available technology into production as the level of technology being applied increases over time.

```
A EDDUR.K=BDDUR.K*WSCF.K                                RD38

BDDUR = Baseline Development Duration (months)
EDDUR = Estimated Development Duration (months)
WSCF = Weapon System Complexity Factor
        (dimensionless)
```

The second difference is that in calculating the production affordability, a shorter term threat is used than for validation or development affordability.

```
A PAFD.K=DPFAQ.K*SMOOTH(PT.JK,12)                        RD36

DPFAQ = Defense Pressure for Acquisition
        (dimensionless)
PAFD = Production Affordability (programs per month)
PT = Production Program Terminations
        (programs per month)
```

The remaining equations in the development sector reflect the same concepts and relationships developed in the validation phase. Figures 2.19 and 2.20 present development phase costing and flow diagrams of the process respectively. A summary of the research and development sector follows the development phase flow diagrams.

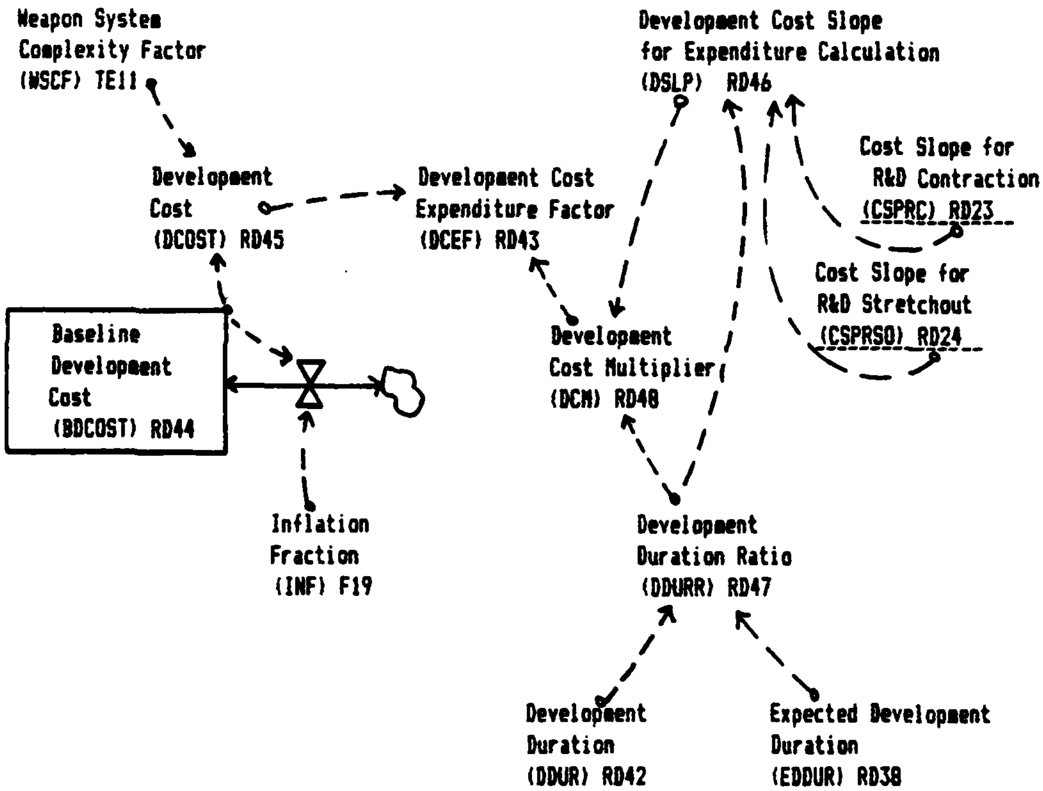

Figure 2.19 Development Costing Flow Diagram

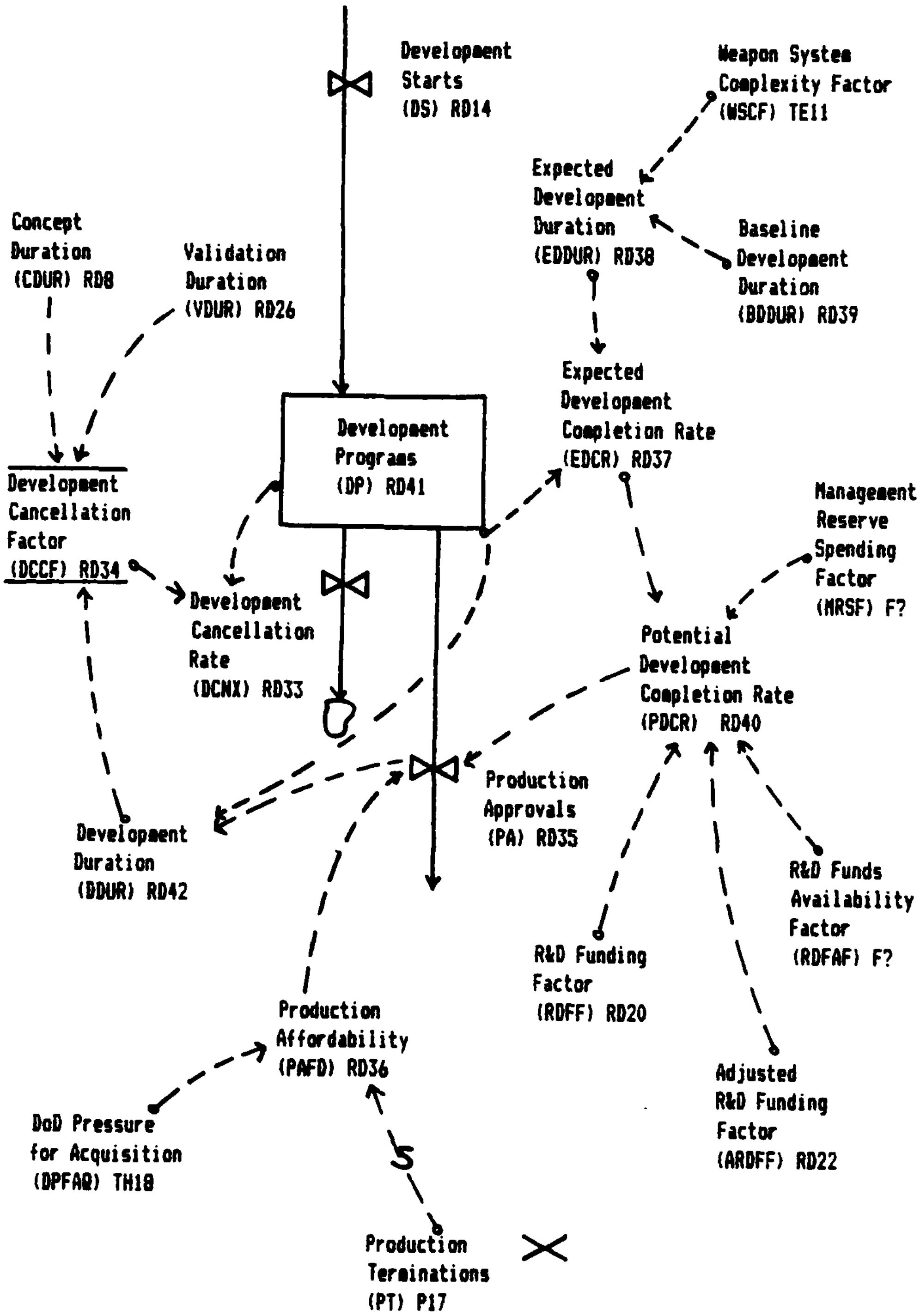

Figure 2.20 Development Phase Flow Diagram

Research and Development Sector Summary. Concepts introduced in research and development include: programs, program progression decisions, affordability, flows of programs through the three phases of R&D, program work accomplishment, and funding effects on work accomplishment. Each of the three phases of R&D have been developed and formulation of equations presented. The research and development sector processes programs through the phases and with final approval for production, programs then flow from the development phase into production.

Production Sector

The production sector encompasses the creation of capability from two sources, new weapon systems and modification of existing weapon systems. The production sector is described in three parts. The production of new capability and the modification of existing forces are each presented, first conceptually and then through the formulation of equations. Closing out the sector discussion is a brief presentation of the equation formulation for the accumulation of US capability.

Production of New Systems. After programs have been approved for production in the R&D sector they flow into the production sector where each program will provide a predetermined amount of capability and then be terminated. The amount of capability obtained from each program is held

constant so that the development of a program through the acquisition system reflects the acquisition of a predetermined amount of capability. This results in decreasing quantities of weapons over time as the weapons become more technologically advanced and it takes fewer "production units" to provide the same capability. A production unit can be equated to a single aircraft or missile. With these assumptions and definition in mind the production of weapon systems will be discussed.

The production of capability can be viewed as a pipeline into which production starts are poured, and after a delay to allow for the production process, capability ready for deployment flows out the other end (see Figure 2.21).

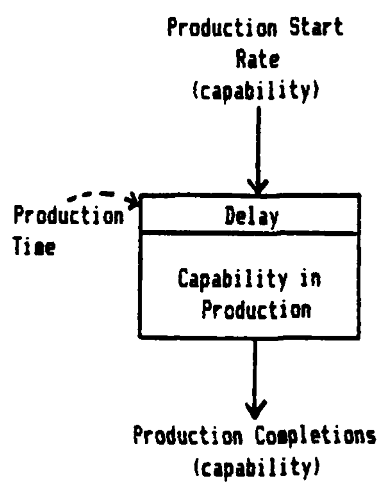

Figure 2.21 Production of Capability

The rate at which capability is started down the pipeline is dependent on the number of programs in production, the rate of production per program, measured in production units, and the level of technology being applied to production.

```
R PRODS.KL=PP.K*ROP.K*PTECH.K                          P1

PRODS = Production Start Rate
        (capability per month)
PP = Production Programs (programs)
PTECH = Production Technology
        (capability per production unit)
ROP = Rate of Production
        (production units per month per program)
```

The outflow from the capability production process is a delayed function of the inflow. The delay function selected for use here is the third order pipeline delay. The characteristic behavior of a third order delay is shown in Figure 2.22. The third order delay was selected because of its availability in the DYNAMO computer language, and its

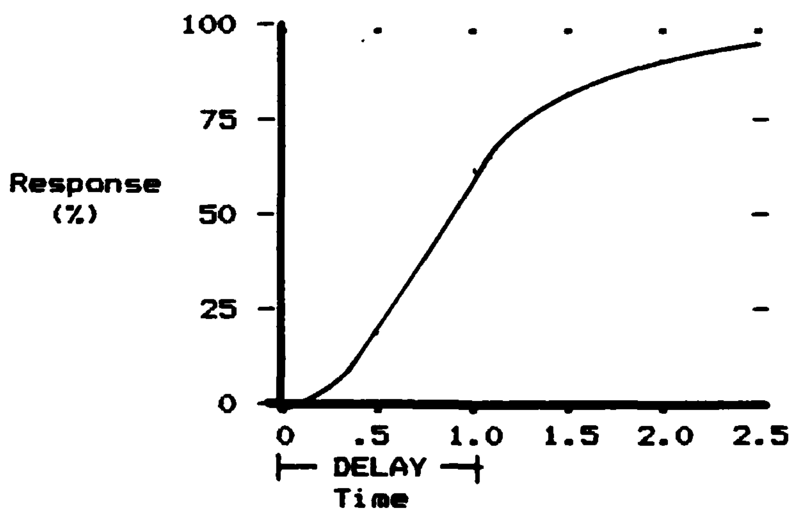

Figure 2.22 Delay Response Characteristics (27:Fig.3.17)

steep response curve. The steep response curve means that the product flowing into the delay will flow out over a narrow range of time around the designated delay time. This was desired to emulate the limited flexibility in the system time between the agreement to purchase weapons and weapons delivery. The pipeline feature of the delay function provides a measure of the current inprocess capability in the delay. Equation P2 determines the rate of completion of capability in the production pipeline. Production time relates to the time between government agreement to purchase the weapons and delivery of the weapons.

```
R PCC.KL=DELAYP(PRODS.JK,PTIME,CAPIP.K)          P2
C PTIME=30                                        P3

CAPIP = Capability in Production (capability)
PCC = Production completion Rate
        (capability per month)
PRODS = Production Start Rate
        (capability per month)
PTIME = Production Time (months)
```

The production starts and completion formulation just presented are depicted in Figure 2.23, Production Pipeline Flow Diagram. Figure 2.23 also depicts the formulations for numerical force calculation, which closely mirrors the capability pipeline. Instead of capability flowing, a count of production units is maintained that will later be used in determining the technological gap between deployed forces and current potential capability and for modification decisions. The size of the force (SOF) is formulated as a

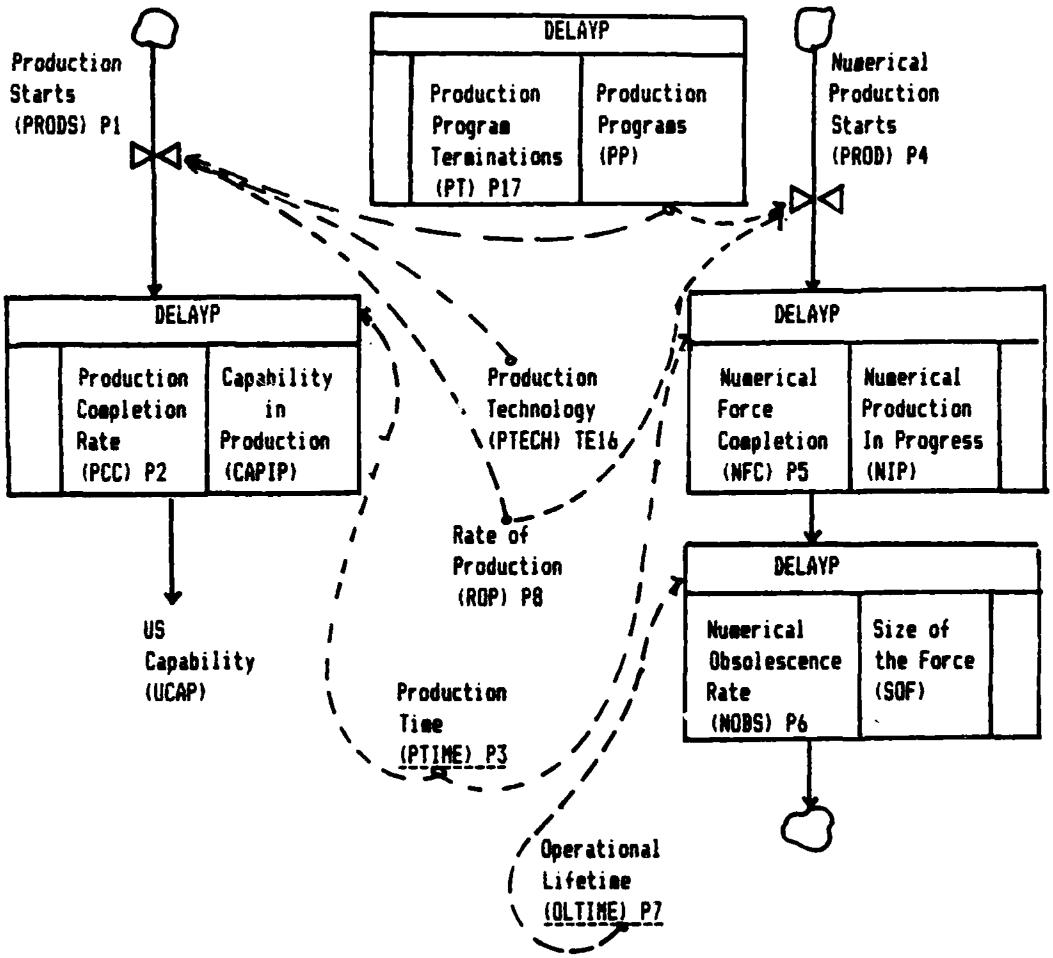

Figure 2.23 Production Pipeline Flow Diagram

pipeline delay with newly deployed forces flowing in, and obsolete forces flowing out (equation P6). Obsolescence is determined as a fraction of the force each time period, dependent on the operational lifetime.

```
R PROD.KL=PP.K*ROP.K                          P4
R NFC.KL=DELAYP(PROD.JK,PTIME,NIP.K)          P5
R NOBS.KL=DELAYP(NFC.JK,OLTIME,SOF.K)         P6
C OLTIME=240                                  P7
```

NFC = Numerical Force Completion Rate
(production units per month)
NIP = Number in Production (production units)
NOBS = Numerical Obsolescence Rate
(production units per month)
OLTIME = Operational Lifetime of Systems (months)
PP = Production Programs (programs)
PROD = Production Rate (production units per month)
PTIME = Production Time (months)
ROP = Rate of Production
(production units per month per program)
SOF = Size of the Force (production units)

The monthly rate of production is calculated by adjusting the desired rate of production to reflect the funds available for production (see Figure 2.24). During

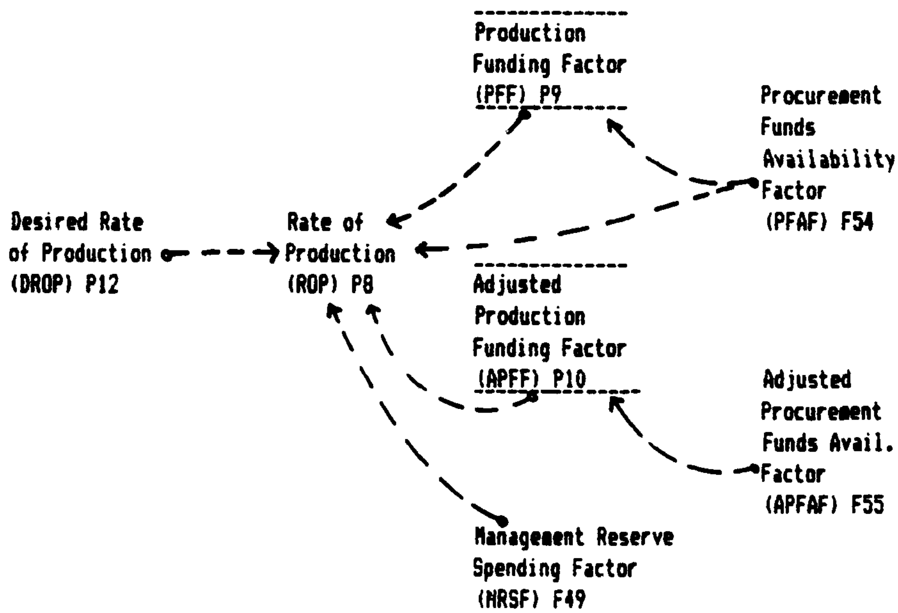

Figure 2.24 Rate of Production Flow Diagram

the course of interviews it became evident that the cost effects of varying the rate of production are significantly different for each program, but that production will

generally cost more for each unit when the rate is changed from the economic production rate. Modeling of the cost differential was accomplished by considering the predetermined desired rate of production to be the economic order rate and charging a penalty for varying that rate. Figure 2.25 reflects the cost multiplier that was used to increase unit costs when production rates were changed.

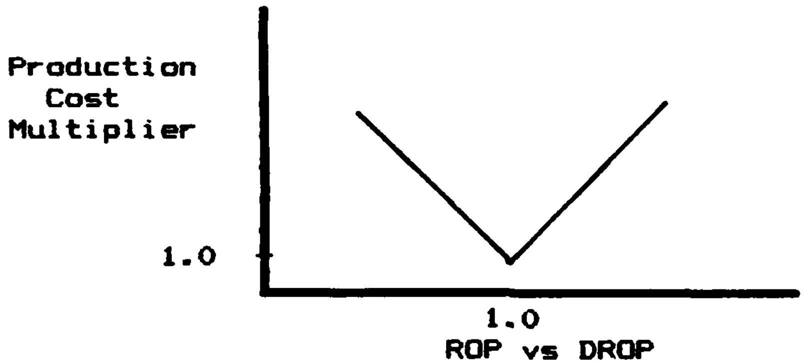

Figure 2.25 Production Costing

The table of production rate adjustment factors (TPRAF) in equation P11 was developed from the diagram in Figure 2.25 using slopes of -.5 and .5. As in the research and development sector, the required management reserve fraction is maintained as long as funding is greater than required, but is used to try to keep up when funding levels for production drop below 100 percent.

```
A ROP.K=DROP.K*MIN(PFF.K,CLIP(APFF.K,1,
        PFAF.K,MRSF.K))                                P8
A PFF.K=TABLE(TPRAF,PFAF.K,.2,2.0,.1)                  P9
A APFF.K=TABLE(TPRAF,APFAF.K,.2,2.0,.1)                P10
T  TPRAF=.07,.215,.295,.38,.48,.58,.69,.82,1.0,
        1.065,1.13,1.19,1.25,1.305,1.36,1.41,
        1.46,1.51,1.56                                 P11
```

APFAF = Adjusted Procurement Funds Availability Factor (dimensionless)
APFF = Adjusted Production Funding Factor (dimensionless)
DROP = Desired Rate of Production (production units per month per program)
MRSF = Management Reserve Spending Factor (dimensionless)
PFAF = Procurement Funds Availability Factor (dimensionless)
PFF = Production Funding Factor (dimensionless)
ROP = Rate of Production (production units per month per program)
SOB = Size of the Buy (production units per program)
TPRAF = Table of Production Rate Adjustment Factors (dimensionless)

The desired rate of production provides the planning base that is used for determining budget and desired operation rates for the production of new weapon systems. The desired rate of production (Figure 2.26) is determined

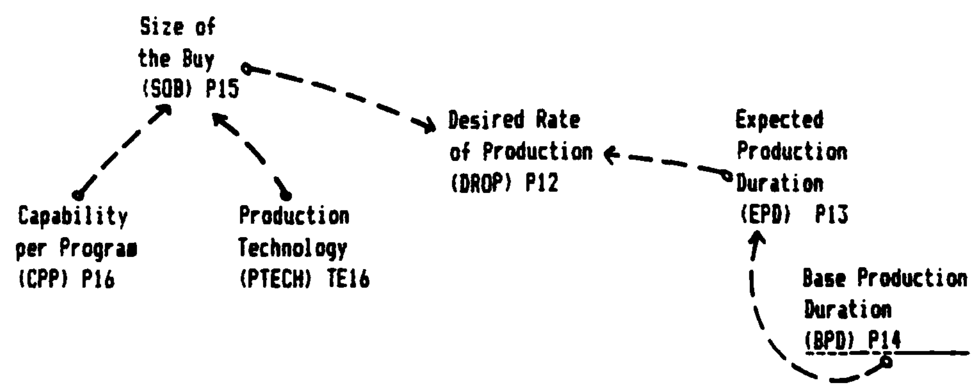

Figure 2.26
Desired Rate of Production Flow Diagram

by comparing the number of production units to be purchased from each program (size of the buy) and the length of time over which the production is to be accomplished (expected production duration). The number of production units to be

obtained from each program is determined by comparing the amount of capability to be purchased from each program (CPP) and the current production technology (PTECH), measured in capability per production unit. The expected production duration is treated as a constant five years for model development.

```
A DROP.K=SOB.K/EPD.K                                    P12
A EPD.K=BPD                                             P13
C  BPD=60                                               P14
A SOB.K=CPP/PTECH.K                                     P15
C  CPP=100                                              P16
```

BPD = Base Production Duration (months)
CPP = Capability per Program (capability per program)
DROP = Desired Rate of Production
(production units per month per program)
EPD = Expected Production Duration (months)
PTECH = Production Technology
(capability per production unit)
SOB = Size of the Buy (capability per program)

Program flow in production is formulated as a third order pipeline delay. Programs flow into the pipeline when approved for production in the R&D sector, remain in the pipeline while in production, and flow out of the pipeline (production terminations) when production of the program is complete. The duration of the delay (PDUR) is dependent on the rate of production (ROP) and the number of production units being produced by each program (SOB). The time of the delay is designed to hold the program in production until the desired amount of capability has been produced by the program.

```
R PT.KL=DELAYP(PA.JK,PDUR.K,PP.K)                P17
A PDUR.K=SOB.K/ROP.K                             P18
```

PA = Production Approval Rate (programs per month)
PDUR = Production Duration (months)
PP = Production Programs (programs)
PT = Production Program Termination Rate
(programs per month)
ROP = Rate of Production
(production units per month per program)
SOB = Size of the Buy
(production units per program)

Production costs are incurred in the model at the time of production start. This is done to model the acquisition system in which procurement funds are obligated when the government contracts for the delivery of production items. The agreement/contracting for production is modeled as occurring at the beginning of production as discussed earlier. The production spending rate is calculated in the financial sector (equation F49). However, the cost elements to be used are determined in the production sector. Cost information needed by the financial sector for spending calculations include the base cost per capability unit (PCOST) and the efficiency with which the money is being spent (PECR). The base production cost per capability unit is determined from an initialized cost per unit and is adjusted for inflation. The production efficiency factor (PECR) is derived from the cost to duration relationship shown in Figure 2.23, and reflects cost increases resulting from not producing at the desired rate.

```
L PCOST.K=PCOST.J+DT*(PCOST.J*INF.J)             P19
A PECR.K=TABLE(TPECR,ROP.K/DROP.K,.1,1.6,.1)     P20
```

```
T   TPECR=1.45,1.4,1.3,1.25,1.2,1.15,1.1,1.05,
          1.0,1.05,1.1,1.15,1.2,1.25,1.3            P21
```

DROP = Desired Rate of Production
(production units per month per program)
INF = Inflation Fraction (fraction per month)
PCOST = Production Cost Factor ($ per capability)
PECR = Production Efficiency Cost Factor
(dimensionless)
ROP = Rate of Production
(production units per month per program)
TPECR = Table of Production Efficiency Cost Factors
(dimensionless)

Modifications. Weapon system modifications are accomplished both to increase capability and to maintain an existing capability. The decision to modify an existing weapon system in the model is made as a response to the size of gap between the average level of technology in operational forces and the technology currently available, and the near term threat. The modification system response is to start a modification program which will gradually try to close a fraction of the existing technology gap. Discussion of the modification process will first present the decision structure for determining the desired rate of modifications and then present the flow of modifications from initiation to addition to US capability.

The information structure used in determining the desired modification start rate is shown in Figure 2.27. The average technology level of an operational weapon (OPTECH), e.g. an airplane, is determined by comparing the total US capability to the number of weapon units included in the capability (equation P22). The average technology in

an operational weapon is used with the level of available technology to determine the existing operational technology gap (OTGAP, equation P23). Modification technology gap fraction (MODTGF, equation P24) is an input constant that estimates the fraction of the gap between available and operational technology that is to be closed by the application of force modifications. The force modification

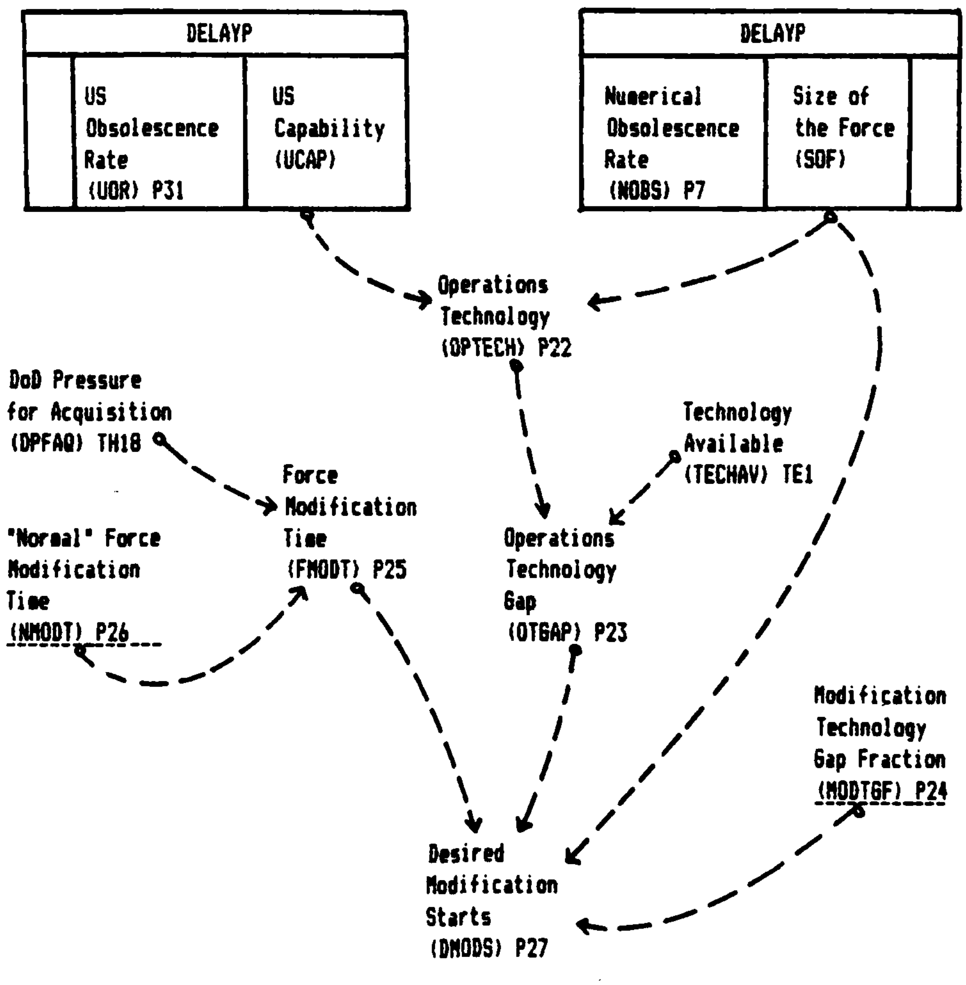

Figure 2.27
Desired Modification Starts Flow Diagram

time (FMODT) is the time span over which the modifications are to be made. The modification time span is determined from the constant, normal force modification time (NMODT), and influenced by the near term threat as depicted by the DoD pressure for acquisition. As shown then in Figure 2.27 and equation P27, the desired modification starts combines the four factors just introduced.

```
A OPTECH.K=UCAP.K/SOF.K                             P22
A OTGAP.K=TECHAP.K-OPTECH.K                         P23
C MODTGF=.1                                         P24
A FMODT.K=NMODT/DPFAQ.K                             P25
C NMODT=240                                         P26
A DMODS.K=SOF.K*OTGAP.K*MODTGF/FMODT.K              P27
```

DMODS = Desired Modification Start Rate
(capability per month)
DPFAQ = DoD Pressure For Acquisition (dimensionless)
FMODT = Force Modernization Time (months)
MODTGF = Modification Technology Gap Fraction
(dimensionless)
NMODT = Normal Modification Time (months)
OPTECH = Operational Technology
(capability per production unit)
OTGAP = Operational Technology Gap
(capability per production unit)
SOF = Size of the Force (production units)
TECHAP = Technology Applied
(capability per production unit)
UCAP = US Capability (capability)

The modification process is formulated as a third order pipeline delay. The decision to begin modification of a weapon system is made, and the modification begins to show in operational forces after time has elapsed for the required R&D, production, and installation of the modification (see Figure 2.28). Modification starts are determined from the desired starts

and adjustment for the procurement funds available. Funds availablity impacts modification starts in the same manner and with the same decision structure developed in production and R&D (see Table 2.1). The significant difference is that there are no penalty or premiums attached for proceeding at other than the desired rate of modification. For the small part that modifications play in the development model, this representation of cost effects seems adequate. After listing of the equations just discussed, the calculation of US capability is presented.

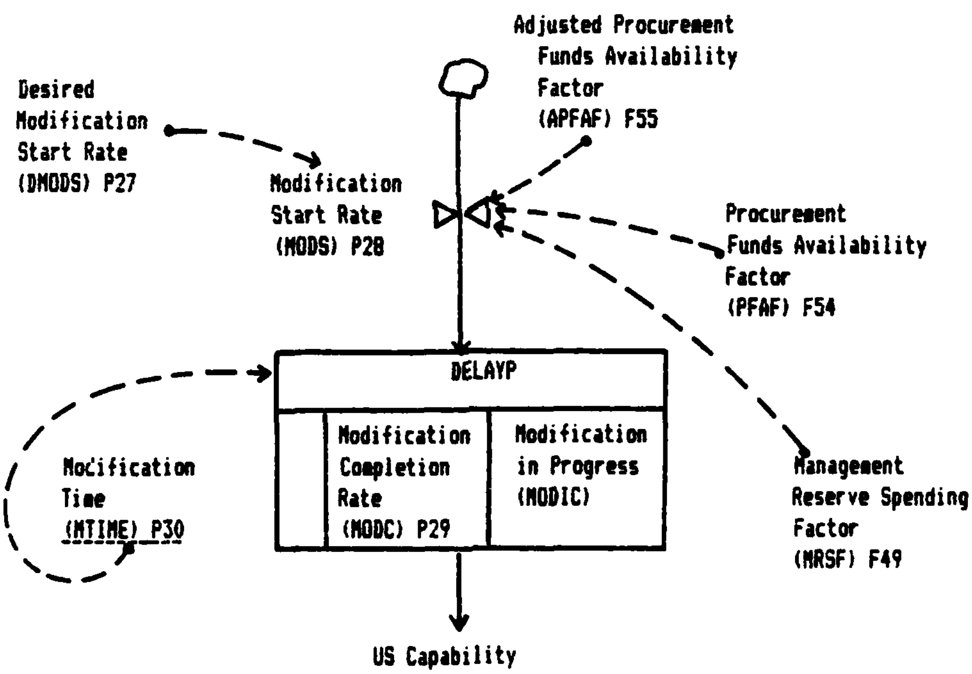

Figure 2.28 Modification Pipeline Flow Diagram

```
R MODS.KL=DMODS.K*MIN(PFAF.K,CLIP(APFAF.K,1,
        PFAF.K,MRSF.K))                              P28
R MODC.KL=DELAYP(MODS.JK,MTIME,MODIP.K)              P29
C  MTIME=24                                          P30
```

APFAF = Adjusted Procurement Funds Availability Factor (dimensionless)
DMODS = Desired Modification Start Rate (capability per month)
MODC = Modification Completion Rate (capability per month)
MODIP = Modification in Progress (capability units)
MODS = Modification Start Rate (capability per month)
MRSF = Management Reserve Spending Factor (dimensionless)
MTIME = Modification Time (months)
PFAF = Procurement Funds Availablity Factor (dimensionless)

<u>Capability Calculation</u>. US capability (see Figure 2.29) is a function of accumulated capability, both from production and modification, less the capability that has become obsolete or removed from the operational inventory.

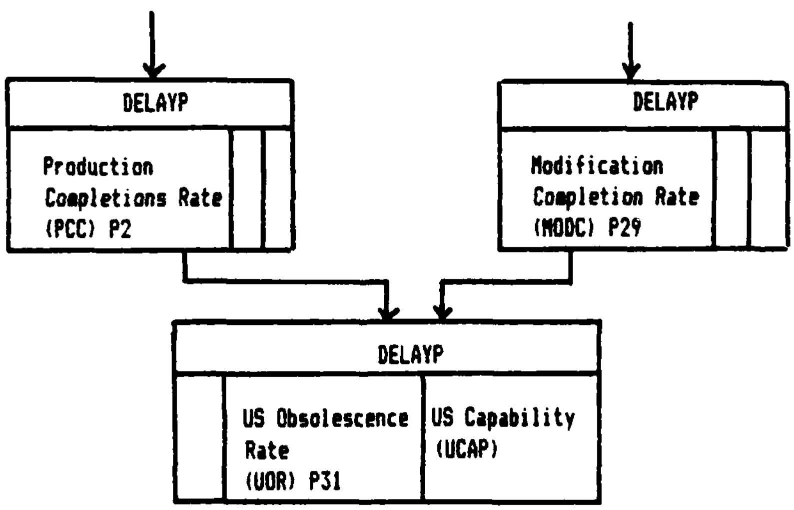

Figure 2.29 US Capability Determination Flow Diagram

The accumulation of capability is modeled as a third order pipeline delay of the input modification and production capabilities over the expected operational life of the

forces. The third order delay was selected over lower order delays to more accurately model potential surges of capability production to proceed through the lifetime as a surge, rather than be averaged out in a few months. The operational lifetime of capability has been modeled as a constant 20 years.

R UOR.KL=DELAYP(PCC.JK+MODC.JK,OLTIME,PCAP.K) P31

MODC = Modification Completion Rate (capability per month)
OLTIME = Operational Lifetime of Forces (months)
PCC = Production Completion Rate (capability per month)
UCAP = Potential Capability (capability)
UOR = US Obsolescence Rate (capability per month)

Production Sector Summary. The production sector depicts the production of capability, both through new weapons and the modification of old weapons to include new technology. The production and modification processes are presented as a third order pipeline delay in which capability starts are input and, after time for processing, capability flows out of the pipeline and is deployed. The R&D and production sectors have introduced the process of acquisition and the environment in which it operates. Information and controls of the acquisition process will be further explained as the financial, technology, and threat sectors are developed.

Financial Sector

The Financial Sector provides the constraining influences of political and economic reality to the acquisition process. This purpose is accomplished by providing information to the other sectors of the model concerning the availability of funds appropriated by the Congress for the acquisition, modification, and operation and support of military forces. The funds availability information is used to control the rate of work accomplishment (R&D progress, production rate, etc.) in the other sectors which, in turn, controls the spending rate.

Sector Overview. Figure 2.30 depicts the process used in the financial sector for determining the availablity of funds. First, the funding requirements and threat are combined to determine the budget requests. The budget requests are then sent to the Congresss, which considers political and economic factors, the threat, and the budget request to determine the appropriations. The money appropriated by the Congress then becomes available to DoD for spending. By comparing the funds required for the desired rate of work accomplishment to the funds available, the financial sector provides information to the other sectors for controlling the amount of work that will be accomplished. The rate of work accomplishment in the R&D and production sectors determines the spending rate, which along with the appropriation rate, determines the level of

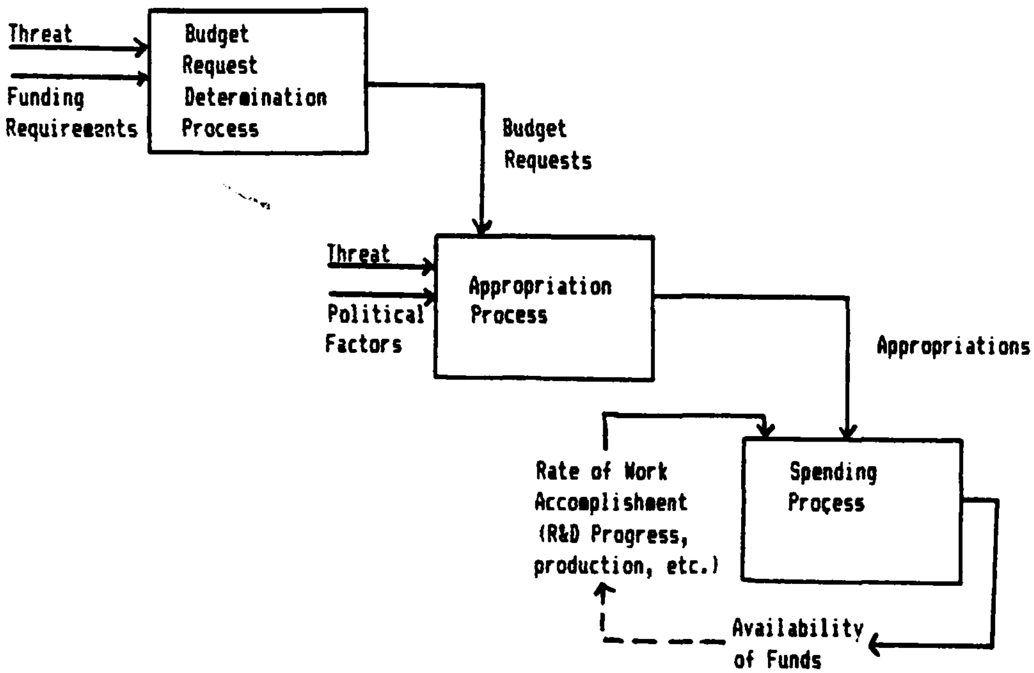

Figure 2.30 Financial Sector Process Diagram

funds available. The financial process is accomplished through the consideration of three distinct categories of funds.

Three types of funds were identified in the model: research and development (R&D), procurement, and operations and support (O&S). the first two categories are equivalent to the Research, Development, Test, and Evaluation (RDT&E) and Procurement appropriations in the DoD budget. The operations and support category is a simplification which includes, in addition to the Operations and Maintenance (O&M) appropriation, the funds for personnel and all other support costs necessary to operate and support the DoD inventory of weapons. Essentially, O&S includes all of the

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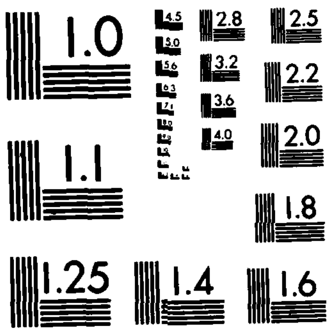


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

remainder of the DoD budget not included under the R&D and procurement categories. For each category of funds, there is a level of funds available which is determined by appropriation and spending rates, as shown in Figure 2.31.

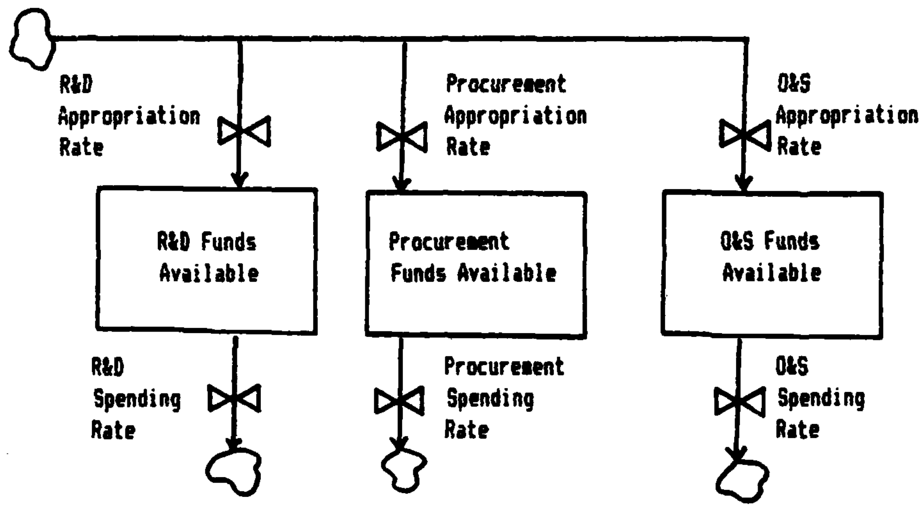


Figure 2.31
Financial Sector Partial Flow Diagram

As discussed previously, each appropriation rate is determined from the budget request, the threat and the political and economic factors which are brought to bear in the Congressional appropriations process. Budget requests for the three categories of funds are determined in the context of the threat faced by the DoD. For research and development, the funding requirements are based upon the cost for programs to proceed on schedule, with the number of programs for which funding is requested being determined from the affordability considerations in the R&D sector. Procurement funding requirements are based on the cost per capability unit for the desired production and modification

rates, with the number of production programs determined from affordability considerations, as was done for R&D. The operations and support budget request is based upon the annual cost per capability unit for operation and support of the amount of capability that the DoD is expected to have in the budget year. The assumption of constant (except for inflation) O&S cost per capability unit was judged in the interviews to be adequate for the purpose of this model. All of the budget requests are computed for one year's expected cost and are adjusted for projected inflation. These projections of funding requirements are made in the Fall, one year prior to the beginning of the budget year to which they apply (34:7).

The budget requests are acted upon by the Congress to determine the annual appropriation for each category of funds. In making its decision, the Congress considers economic and political factors, the threat, and the size of the budget request. The nature of the political and economic factors was discussed in the interviews, with general agreement that the key factors in determining the results of the appropriation process are the short-term threat, the size of the DoD budget request relative to the gross national product, the demand for non-defense federal spending, and the fiscal policy needs of the economy. A few interviewees felt that the percentage growth in the DoD budget from year to year, with the percentage allowed being

driven by the threat, should be used. However, most interviewees agreed that the GNP fraction, when combined with the other effects included in the model, would provide a better surrogate for the Congressional process. These four factors are combined into a single factor, the funds appropriation ratio, which determines all three appropriations from the budget request. During the interviews, the appropriation for and priority of one category of funds over another was discussed, but no consensus or evidence was available to support a specific decision or policy structure regarding priorities of funding for the three categories. All three categories therefore receive the same priority in the appropriation process.

The annual appropriation flows into the level of funds available for each funding category, and is then available for spending. R&D spending occurs based upon the number of programs in each phase and the cost per program per month for the work that is accomplished. The rate of work accomplishment is adjusted based upon a comparison of the amount of funds that would be required for the remainder of the year for programs to remain on schedule and the funds available. Procurement spending is based upon the cost per capability unit for production and modification starts, under the assumption that funds are obligated once work has begun. The rates of production and modification are adjusted for funding availablity in a similar manner as the

rate of R&D progress. Spending of operations and support money is assumed, rather simplistically, to occur at a linear rate through the fiscal year. For the purpose of studying the DoD acquisition system, this simplification is reasonable since the major impact of operations and support costs occurs simply as a result of their presence in the DoD budget and the resulting impact on the appropriations for R&D and procurement, rather than the precise spending pattern of operations and support funds. The comparison of available to required O&S funds is used to determine the need for and size of the supplemental appropriation request. O&S is the only category of funds in the model for which a mechanism was provided for supplemental appropriations. Interview discussions determined that O&S is the only category for which supplemental appropriations are normally requested.

The discussion of the financial sector formulation is divided into three areas: budget request determination, economic and political factors analysis, and appropriation and spending. The next three sections discuss the details of each of these three areas of the model.

Budget Request Determination. As discussed earlier, the budget requests upon which Congress acts are based upon the funding requirements in the budget year as they were projected one year previously. Thus for each category of funds, the funding requirements are determined for the year

beginning one year in the future, then delayed by the budgetary delay time to obtain the budget request upon which Congress will act. The determination of the projected funding requirements differs for each category of funds, as discussed in the next few paragraphs.

The research and development funding requirements are determined by projecting the affordable number of programs in each phase of the R&D process, and the cost to maintain this number of programs on schedule. As shown in Figure 2.32, the requirements are determined for each phase of the R&D process and then summed to obtain the total R&D funding requirements.

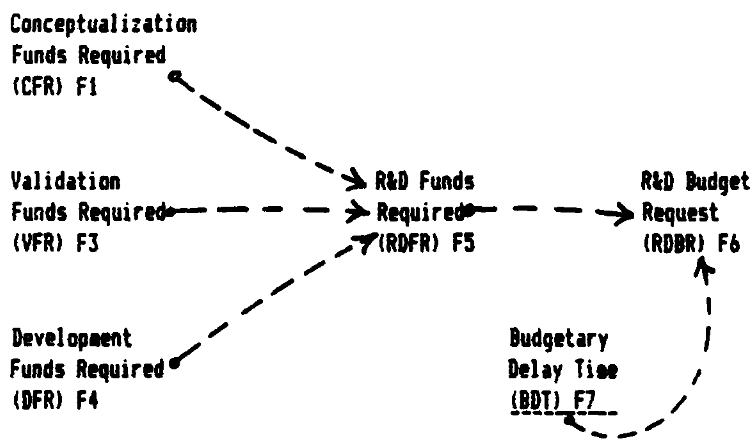


Figure 2.32 Research and Development Budget Request Determination

The method for determining the number of programs for which funding will be requested is based upon the affordability concept that was introduced in the discussion of the R&D sector. The affordability constraints allow the rate of program flow into a phase to be equal to the pressure for

R&D multiplied by the average rate of flow out of that phase. Now, if these rates were to continue into the future, the number of programs in the phase would be multiplied by the pressure for R&D after a time period equal to the duration of the phase. Therefore, the number of programs midway through the budget year, which would approximate the average number of programs for the year, could grow by a factor of :

1+(PRD-1)*(BDT+6)/(expected duration of the phase)

This rate of growth is the affordable rate of growth in the R&D sector, and the policy is to request sufficient funds to support this growth rate.

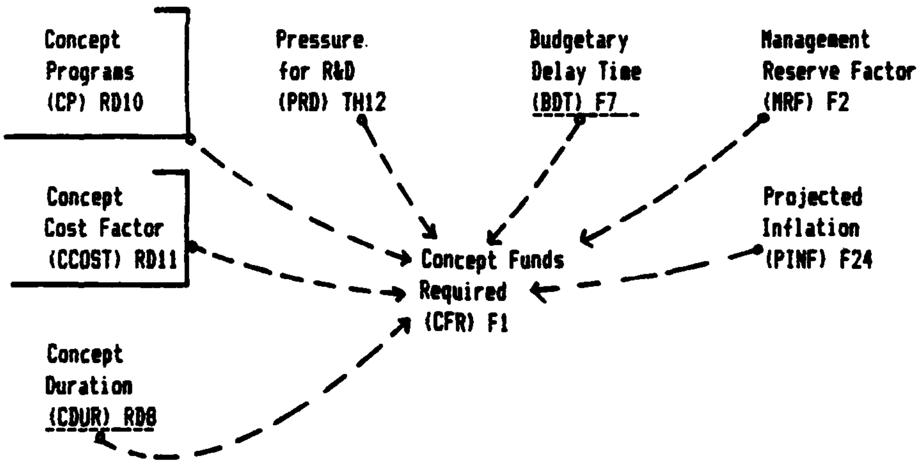


Figure 2.33
Concept Funds Requirements Determination

To compute the concept funds required (see Figure 2.33), the present level of concept phase programs is adjusted by the growth factor derived above to project the number of programs halfway through the budget year. The

concept phase is the current monthly cost per program and is adjusted for projected inflation and multiplied by twelve to obtain the annual cost. A management reserve factor is applied to request funds to cover unforecast inflation and other cost growth. The validation and development funding requirements (equations F3 and F4) are computed in the same manner as the concept funding requirements.

```
A CFR.K=CPU.K*(1+(PRD-1)*(BDT+6)/CDUR.K)*
        CCOST.K*(1+PINF.K)*MRF                    F1
A VFR.K=VPU.K*(1+(PRD-1)*(BDT+6)/EVDUR.K)*
        VCOST.K*(1+PINF.K)*MRF                    F3
A DFR.K=DPU.K*(1+(PRD-1)*(BDT+6)/EDDUR.K)*
        DCOST.K*(1+PINF.K)*MRF                    F4
```

BDT = Budgetary Delay Time (months)
CCOST = Concept Cost Factor
($ per program per month)
CDUR = Concept Duration (months)
CFR = Concept Funds Required in Budget Year ($)
CPU = Concept Programs (programs)
DCOST = Development Cost Factor
($ per program per month)
DFR = Development Funds Required in Budget Year ($)
DPU = Development Programs (programs)
EDDUR = Estimated Development Duration (months)
EVDUR = Estimated Validation Duration (months)
MRF = Management Reserve Factor (dimensionless)
PINF = Projected Inflation for the Budget Year
(dimensionless)
PRD = Pressure for R&D (dimensionless)
VCOST = Validation Cost Factor
($ per program per month)
VFR = Validation Funds Required in Budget Year ($)

The requirements of the three phases of R&D are summed to obtain the R&D funding requirements. The R&D budget request is then computed as a delayed response to the R&D funding requirement to allow for the time between budget formulation and appropriation.

```
A RDFR.K=CFR.K+VFR.K+DFR.K                          F5
A RDBR.K=DLINF3(RDFR.K,BDT)                         F6
C BDT=12                                            F7
```

BDT = Budgetary Delay Time (months)
CFR = Concept Funds Requirements ($)
DFR = Development Funds Required in Budget Year ($)
RDBR = R&D Budget Request ($)
RDFR = R&D Funds Required ($)
VFR = Validation Funds Required in Budget Year ($)

The procurement funds required and budget request are determined by projecting the amount of production and modifications which will occur in the budget year and the costs of each (see Figure 2.34). Sufficient funds are requested for desired production and modification rates. The production funds requirements are determined in the same manner as

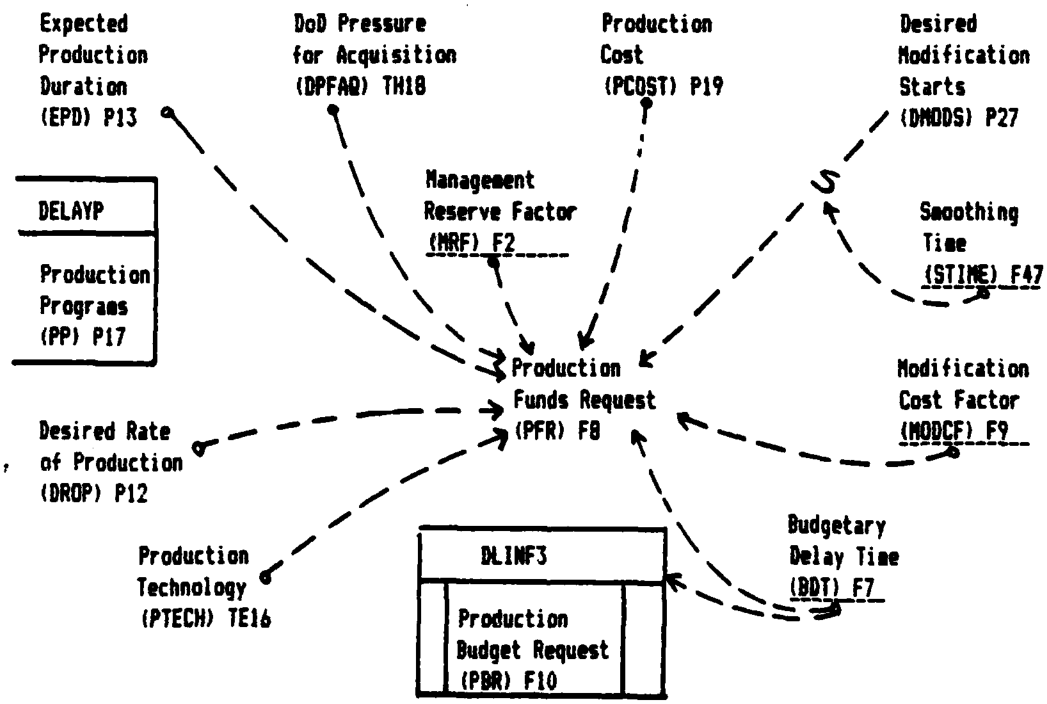


Figure 2.34
Procurement Funds Requirements Determination

for R&D, except that the DoD pressure for acquisition (DPFAQ), a short-term threat, is substituted for the longer-term pressure for R&D (PRD). The cost of production is estimated based upon the desired rate of production (DROP) and the current level of production technology. The desired rate of modification starts is assumed to continue at its average rate over the recent past. The modification cost per capability unit added is a factor (greater than one) multiplied by the production cost per capability unit, since there is usually some development cost incurred in addition to the actual production cost incurred for a modification. The procurement budget request is determined from funding requirements in the same manner as the R&D budget request.

```
A PFR.K=((PPU.K*(1+(DPFAQ.K-1)*(BDT+6)/EPD.K)*
        PTECH.K*DROP.K+SMOOTH(DMODS.K,STIME)*
        MODCF)*PCOST.K*12*(1+PINF.K)*MRF          F7
A PBR.K=DLINF3(PFR.K,BDT)                         F8
```

BDT = Budgetary Delay time (months)
DMODS = Desired Modification Start Rate (capability units per month)
DPFAQ = DoD Pressure for Acquisition (dimensionless)
DROP = Desired Rate of Production (production units per month per program)
EPD = Estimated Production Duration (months)
MODCF = Modification Cost Factor (dimensionless)
MRF = Management Reserve Factor (dimensionless)
PCOST = Production Cost Factor ($ per capability unit)
PFR = Procurement Funds Required in Budget Year ($)
PINF = Projected Inflation for the Budget Year (dimensionless)
PPU = Production Programs (programs)
PTECH = Production Technology (capability units per production unit)
STIME = Smoothing Time (months)

Operations and Support funding requirements are computed based upon the cost to operate and support the expected US capability in the budget year. As shown in Figure 2.35, the amount of capability in the budget year is projected using the average rate of capability growth in the past year. The assumption is that the fractional growth rate will continue. The instantaneous capability growth fraction (ICAPGF) is determined by dividing the net rate of change in potential capability (PCC+MODC-UOR) by the

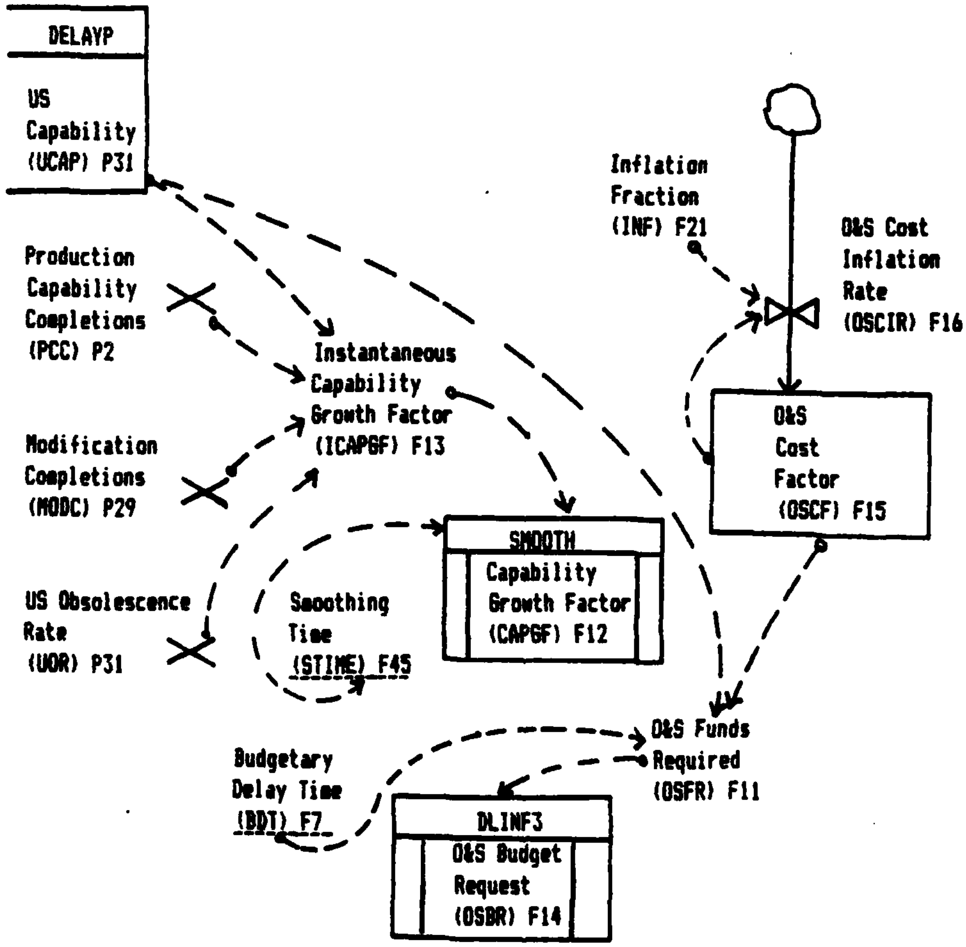


Figure 2.35 Operations and Support Requirements Determination Flow Diagram

potential capability. The average of this rate for the past year is added to one to obtain the factor by which the potential capability is growing each month. Since there are BDT+6 months between the present time and the middle of the budget year, the growth factor is taken to that power to project the expected amount of growth in the US capability. The projected capability is multiplied by the O&S cost factor, which is the monthly cost to operate and support one capability unit. The result is adjusted for inflation and multiplied by twelve to obtain the O&S funds required for the budget year. The O&S budget request is determined as a delayed value of the funds requirements, as were the R&D and procurement budget requests. Following the listing of O&S budget request equations, the economic and political factors that impact the appropriation process will be presented.

```
A OSFR.K=UCAP.K*CAPGF.K**(BDT+6)*OSCF.K*12*
        (1+PINF.K)                                  F11
A CAPGF.K=1+SMOOTH(ICAPGF.K,STIME)                  F12
A ICAPGF.K=(PCC.JK+MODC.JK-UOR.JK)/UCAP.K           F13
A OSBR.K=DLINF3(OSFR.K,BDT)                         F14
L OSCF.K=OSCF.J+DT*OSCIR.JK                         F15
R OSCIR.KL=OSCF.K*INF.K                             F16
```

BDT = Budgetary Delay Time (months)
CAPGF = Capability Growth Factor
(fraction per month)
ICAPGF = Instantaneous Capability Growth Factor
(fraction per month)
INF = Inflation Fraction (fraction per month)
MODC = Modification Completion Rate
(capability per month)
OSBR = O&S Budget Request ($)
OSCF = O&S Cost Factor
($ per capability unit per month)
OSCIR = O&S Cost Inflation Rate
($ per capability unit per month per month)

OSFR = O&S Funds required for the Budget Year ($)
PCC = Production Completion Rate
(capability per month)
PINF = Projected Inflation for the Budget Year
(dimensionless)
STIME = Smoothing Time (months)
UCAP = US Capability (capability)
UOR = US Obsolescence Rate (capability per month)

<u>Economic and Political Factors</u>. This section of the financial sector develops the economic and political pressures that are combined with the threat, as perceived by Congress, to determine the portion of the DoD budget request that is appropriated. Figure 2.36 depicts the process by which four pressures on the appropriation process are developed and combined together to determine the funds appropriation ratio. The formulation of the funds appropriation ratio is shown below.

```
A FAR.K=TP.K*GNPP.K*FPP.K/PNDF.K                F25
```

FAR = Funds Appropriation Ratio (dimensionless)
FPP = Fiscal Policy Pressure (dimensionless)
GNPP = GNP Pressure (dimensionless)
PNDF = Pressure for Non-Defense Funds (dimensionless)
TP = Threat Pressure for DoD Funds (dimensionless)

The economic and political factors center around the US GNP and its growth rate. The US GNP, measured in current dollars, grows at a rate that is equal to the combined effects of real growth and inflation. The cyclical real GNP growth and constant inflation shown in equations F20 and F21 were used as a baseline during model testing to create a varying economic climate. The projected inflation for the

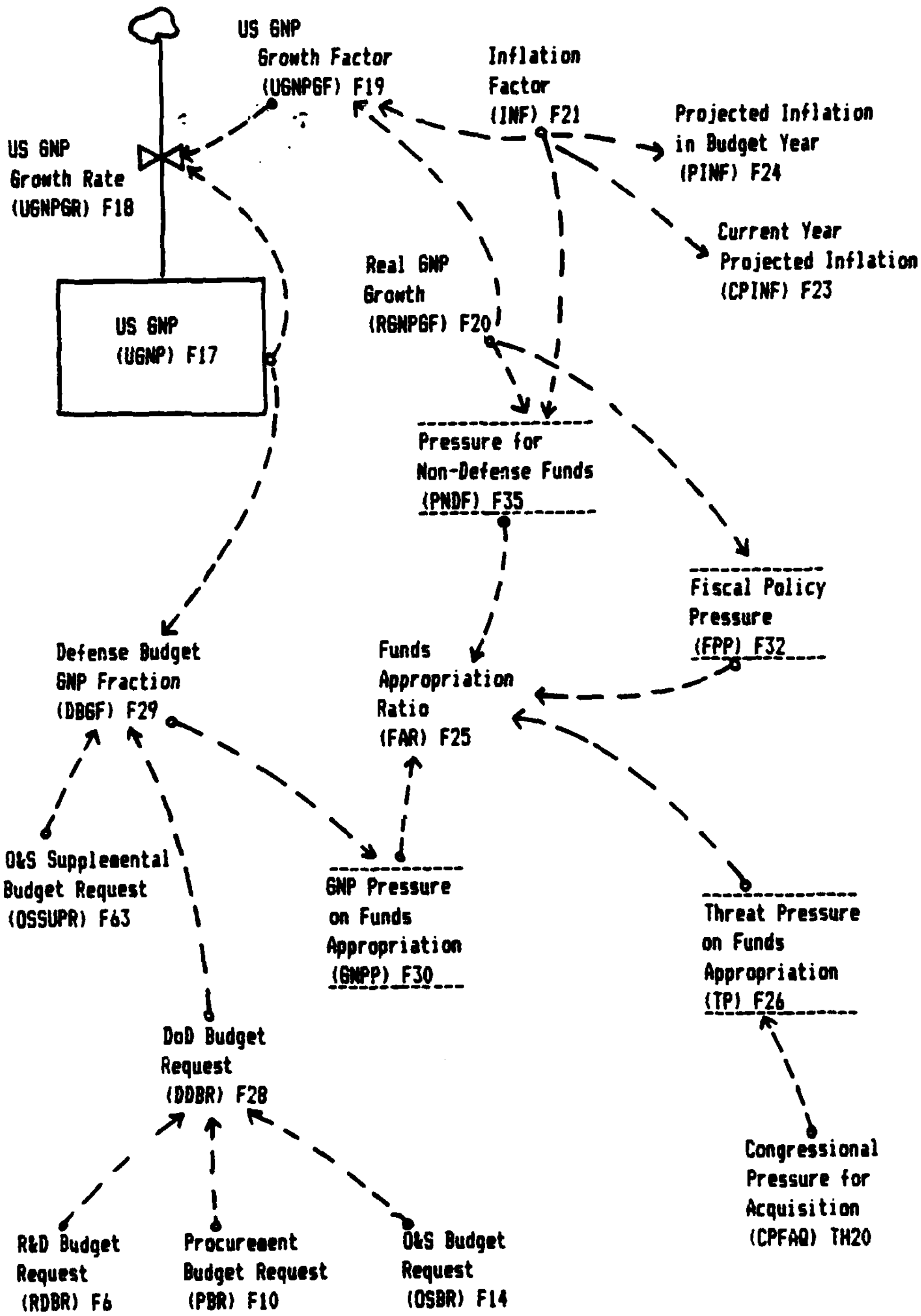


Figure 2.36
Political and Economic Factors
Flow Diagram

budget year is developed in the same fashion used for the growth of programs for R&D budget request, as discussed earlier. Different economic scenarios may be substituted into the model as desired. The following equations determine the GNP and values for inflation used in the model.

```
L UGNP.K=UGNP.J+DT*(UGNPGR.JK                        F15
R UGNPGR.KL=UGNP.K*UGNPGF.K                          F16
A UGNPGF.K=RGNPGF.K+INF.K                            F17
A RGNPGF.K=.0025+.0035*SIN(6.238*TIME.K/72)          F18
A INF.K=INFC                                         F19
C  INFC=.01                                          F20
A CPINF.K=.9*INF.K                                   F21
A PINF1.K=(1+.9*INF.K)**(BDT+6)-1                    F22
```

BDT = Budgetary Delay Time (months)
CPINF = Current Year Projected Inflation (fraction per month)
INF = Inflation Fraction (fraction per month)
INFC = Inflation Constant (fraction per month)
PINF1 = Projected Inflation for the Budget Year (dimensionless)
RGNPGF = Real GNP Growth Fraction (fraction per month)
UGNP = US GNP ($)
UGNPGF = US GNP Growth Fraction (fraction per month)
UGNPGR = US GNP Growth Rate ($ per month)

The four factors that determine the DoD funds appropriation ratio are computed in the model using table functions. The values in the table functions were determined using information from the interviews and a method of estimation for system dynamics table functions outlined by Graham (17:128). The basic procedure is to estimate the value and slope of the function at each extreme and the mid-range value, then connect these points with a smooth curve. It was determined in the interviews that DoD

normally gets between 93 and 98 percent of the amount in the President's Budget. In follow-up discussions, it was found that this range of values is not absolute, and that under extreme conditions might be slightly greater than one, or considerably lower than 93 percent. The table functions were therefore constructed so that the DoD funds appropriation ratio will, under normal circumstances, range from .93 to .98, with the possibility, under extreme and unlikely conditions, of obtaining values from about .85 to 1.01. The next few paragraphs describe how each table function was estimated.

The table for the threat pressure on DoD funds was constructed so that when the threat, as perceived by Congress through the Congressional pressure for acquisition, is at its minimum possible value the DoD would get 93 percent of the amount in the President's Budget, assuming the other factors are at unity. A threat of 1.4, which is a fairly high value, was assigned a table value of .98, which is the high end of the normal range. If the threat would be extremely high, say 2.0, the table function returns a value of 1.005, meaning that if the other pressures are at unity, the DoD would get half a percent more than requested in the budget. It was learned in the interviews that this is not without historical precedent; the Congress actually did this in the late 1950's when it was perceived that the Eisenhower budget did not respond strongly enough to the

presumed Soviet ICBM capability after launch of Sputnik. It is believed that the slope of the function is shallow at both ends and steeper in the middle. This shape would reflect a tendency to disbelieve that a threat exists until it is large enough that it cannot be denied, and a tendency to add very little additional money when the threat increases from a high value. These considerations led to the use of a table function shown graphically in Figure 2.37. The equations which implement this function are listed on the next page.

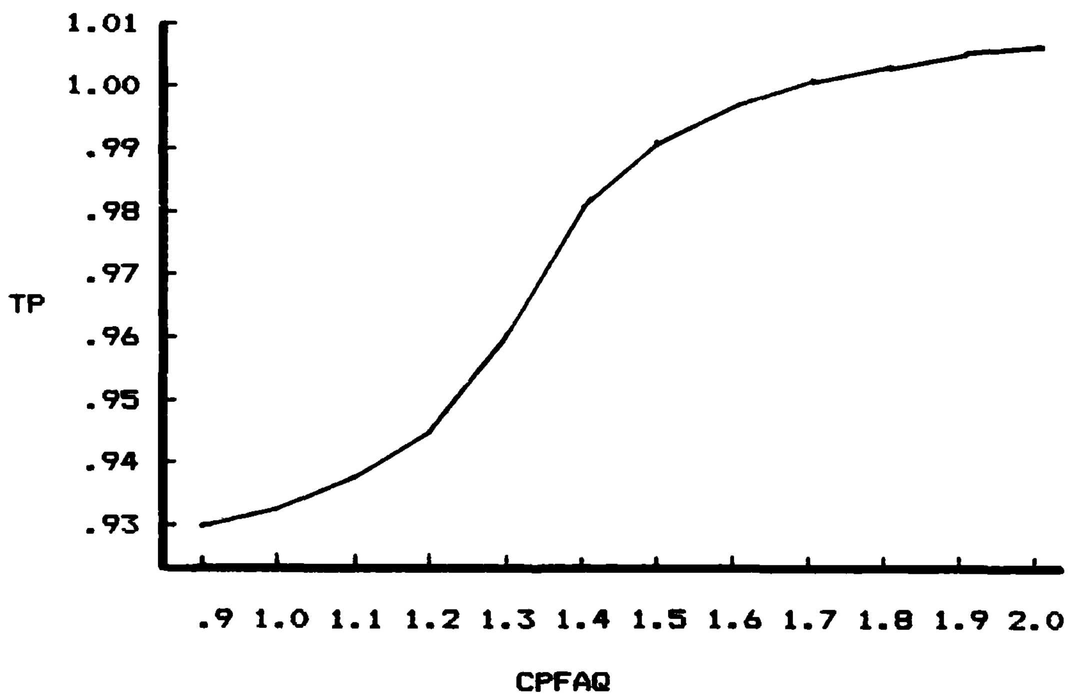


Figure 2.37
Threat Pressure on
Funds Appropriation Ratio

```
A TP.K=TABLE(TTP,CPFAQ.K,.9,2.0,.1)                       F26
T  TTP=.93,.932,.936,.944,.96,.98,.99,.996,1.0,
       1.002,1.004,1.005                                  F27
```

CPFAQ = Congression Pressure for Acquisition (dimensionless)
TP = Threat Pressure on Funds Appropriation (dimensionless)
TTP = Table of Threat Pressures (dimensionless)

The GNP pressure on the DoD funds appropriation ratio recognizes that the larger the DoD budget as a fraction of the US GNP, the more likely that it will be cut by the Congress. The table was constructed so that if the DoD budget request is five percent of the GNP, there will be no effect. The table yields a slight increase in the appropriations rate if the defense budget GNP fraction is less than five percent, and decrease when the fraction is more than five percent. The negative slope of the table function is believed to grow progressively steeper for larger fractions of the GNP being requested. The table function shown in Figure 2.38 reflects the above considerations, and is implemented in the following equations:

```
A DDBR.K=RDBR.K+PBR.K+OSBR.K                              F28
A DBGF.K=(DDBR.K+SUM(OSSUPR.K))/UPNP.K                    F29
A GNPP.K=TABLE(TGNPP,DBGR.K,.03,.07,.01)                  F30
T  TGNPP=1.005,1.003,1.0,.99,.95                          F31
```

DBGF = Defense Budget as GNP Fraction (dimensionless)
DDBR = DoD Budget Request ($)
GNPP = GNP Pressure on Funds Appropriation (dimensionless)
OSSUPR = O&S Supplemental Funds Request ($)
PBR = Procurement Budget Request ($)
RDBR = R&D Budget Request ($)

TGNPP = Table of GNP Pressure (dimensionless)
UGNP = US Gross National Product ($)

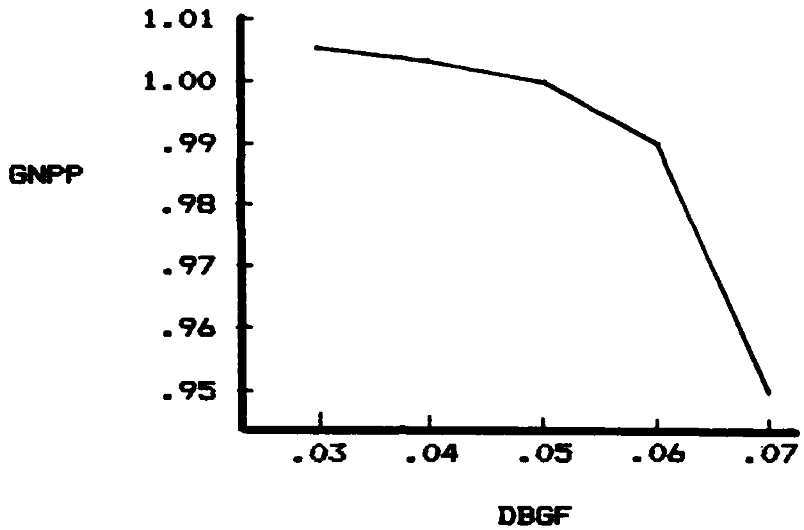


Figure 2.38
Table of GNP Pressure on the
Funds Appropriation Ratio

The fiscal policy effect on the funds appropriation ratio recognizes that since the DoD budget is one of the relatively more controllable aspects of the Federal budget, it is often used as an instrument of fiscal policy. This effect is captured in the model by means of two table functions. The first table, table of fiscal policy effect on DoD funds (Figure 2.39), captures the effect of the real GNP growth rate, which is a measure of whether the economy is in a recession. In the absence of inflation, the tendency to cut the defense budget is reduced when the economic growth slows. This effect is not believed to be capable of causing the DoD to receive more than requested, so the maximum value of the table function is one. Under very good economic

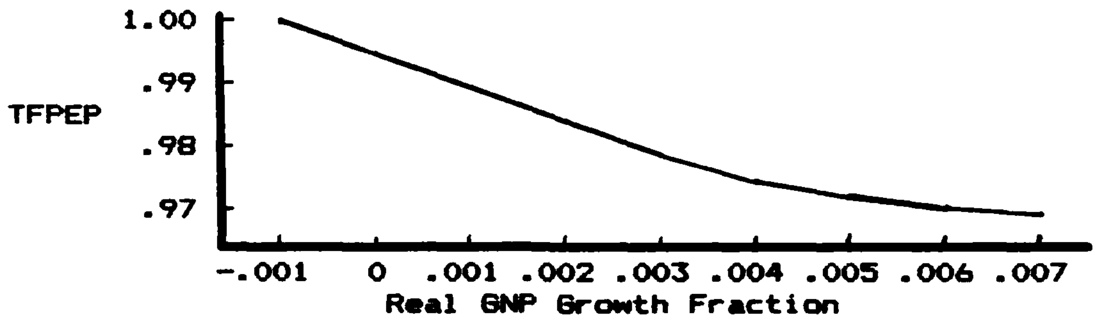


Figure 2.39
Table of the Fiscal Policy Effect
on DoD Appropriations

conditions the Congress might be predisposed to cut the defense budget by as much as three percent, and the cut would be about two percent in the middle range of the table. The slope of this curve is believed to be steeper on the recessionary side of the scale. The second table, Figure 2.40, captures the effect of inflation on fiscal policy. As inflation increases, the Congress will tend to reduce the percentage of the DoD request which is appropriated, in an attempt to control the inflation. Under conditions of

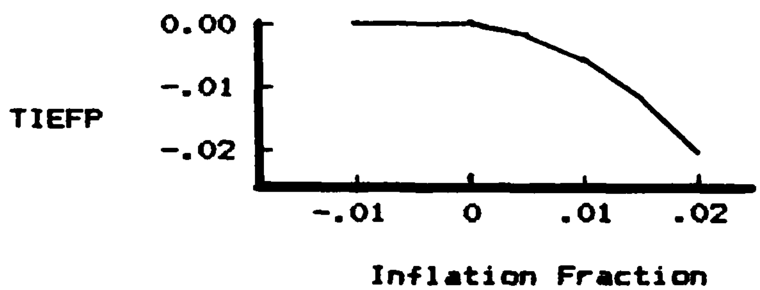


Figure 2.40
Table of Inflation Effect on Fiscal Policy

deflation (negative inflation), however, this effect is not belived to be capable of causing the appropriation to be greater than the budget request. The slope of the function is believed to become progressively steeper for increasing inflation rates. The functions in Figures 2.39 and 2.40 are combined in the fiscal policy pressure on DoD appropriations ratio.

```
A FPP.K=TABLE(TFPEP,RGNPGF.K,-.0001,.0007,.0001)+
        TABLE(TIEFP,INF.K,-.01,.02,.005)              F32
T  TFPEP=1.0,.994,.988,.98,.976,.974,.972,.97         F33
T  TIEFP=0,0,0,-.002,-.006,-.012,-.02                 F34
```

FPP = Fiscal Policy Pressure for DoD Appropriation (dimensionless)
INF = Inflation Fraction (fraction per month)
RGNPGF = Real GNP Growth Fraction (fraction per month)
TFPEP = Table of Fiscal Policy Effect on Appropriations (dimensionless)
TIEFP = Table of Inflation Effect on Appropriations (dimensionless)

The final pressure on the appropriations ratio is the pressure for non-defense funds. This pressure recognizes that when a recession occurs, as measured by a decrease in the real GNP growth fraction, the demand for non-defense federal spending, such as food stamps and unemployment benefits, increases, resulting in a pressure to cut the DoD budget. Also, since most of these programs are indexed to inflation, the pressure will be higher in the event of inflation. It was determined that the strength of this effect is about the same as the fiscal policy effect in the absence of inflation. Therefore, it was constructed

similarly to the fiscal policy effect described above, with a basic table function for pressure for non-defense funds and another table to modify the value to reflect the effect of inflation. The table of pressure for non-defense funds has exactly the same values as the table of fiscal policy effect on appropriation (Figure 2.39). These two factors cancel one another in the absence of inflation, and could theoretically be removed from the model. However, the two factors are included in the model for three reasons. First, the factors more accurately reflect the structure of the real system. Second, their inclusion allows the model user to change the relative strength of the two effects. Finally, the use of the two factors produces another effect that would be more difficult to capture otherwise. For a given amount of inflation, the model structure causes a larger reduction from the DoD budget request when the economy is growing rapidly than when it is contracting. This is typical of the real system, in which the concern for inflation is lessened when there are large numbers on the unemployment rolls, but once the recovery is well underway, the emphasis shifts toward fighting inflation. This behavior results in the model from the fact that the inflation effect on fiscal policy is negative, while the inflation effect on non-defense spending (TIEND) is positive. Since the fiscal policy effect is in the numerator, and the pressure for non-defense spending is in the denominator of

the funds appropriation ratio (equation F25), the result is an amplification of the inflation effect when the GNP growth rate is higher. (This is demonstrated by comparing the result at the extremes of the table, with inflation of two percent per month. During a recession, the net result is (1-.02)/(1+.02)=.9608 , while during a recovery the net result is (.97-.02)/(.97+.02)=.9595.) The table function for the inflation effect on pressure for non-defense funds is shown in Figure 2.41 and the following equations implement the concepts described.

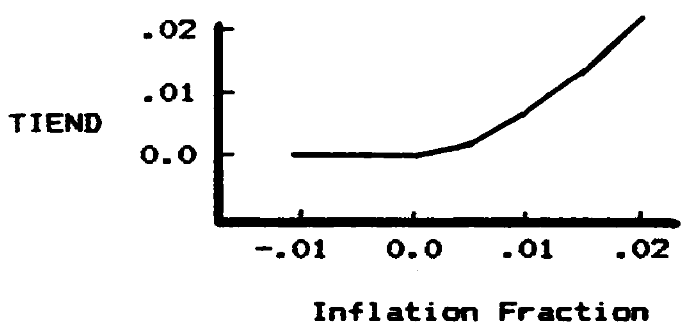


Figure 2.41
Table of Inflation Effect on
Non-Defense Spending

```
A PNDF.K=TABLE(TPNDF,RGNPGF,-.001,.007,.001)+
        TABLE(TIEND,INF.K,-.01,.02,.005)            F35
T  TPNDF=1.0,.994,.988,.984,.98,
        .976,.974,.972,.97                          F36
T  TIEND=0,0,0,.002,.006,.012,.02                   F37
```

INF = Inflation Fraction (fraction per month)
PNDF = Pressure for Non-DoD Funds (dimensionless)
RGNPGF = Real GNP Growth Fraction
(fraction per month)
TIEND = Table of Inflation Effect on Non-Defense
Spending (dimensionless)
TPNDF = Table of Pressure for Non-DoD Funds
(dimensionless)

Appropriation and Expenditure. The annual appropriation of funds for each of three categories is determined by combining the Funds Appropriation Rate and the budget request. Within the appropriation and expenditure portion of the financial sector, annual appropriations are made, funds expenditure and expenditure control calculations performed, and for the O&S category only, supplemental funds request accomplished as required. Each of the three categories of funds will be discussed, beginning with R&D.

The research and development appropriations and spending rates are determined from the factors shown in Figure 2.42. The appropriation is computed by multiplying

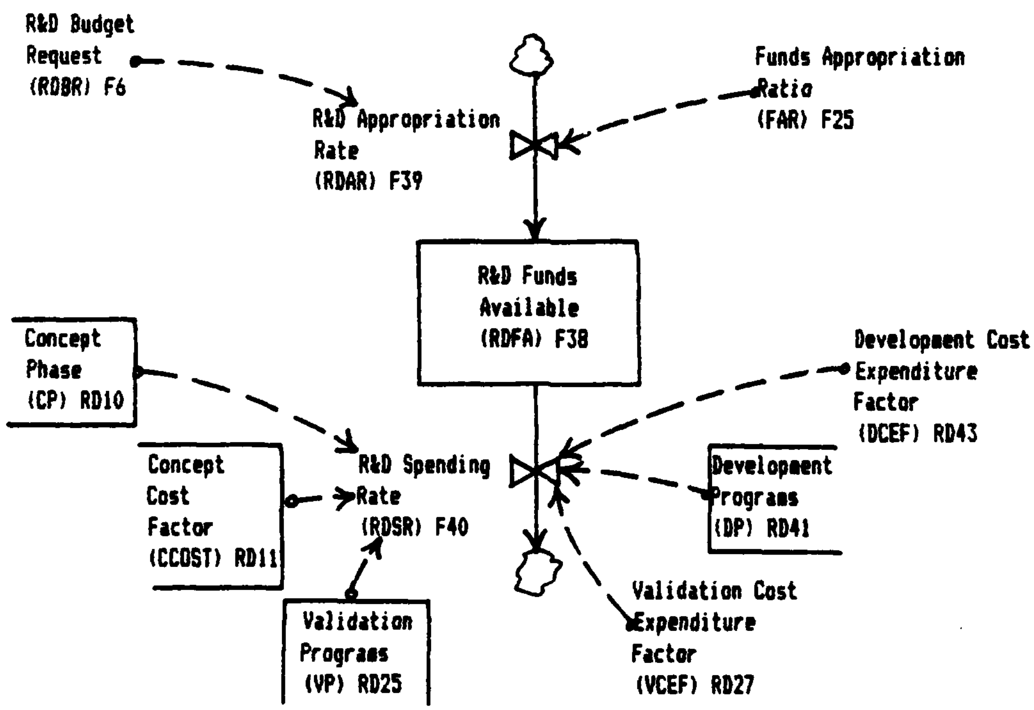


Figure 2.42 Partial Research and Development Appropriation and Spending Flow Diagram

the R&D budget request by the funds appropriation ratio. To convert this dollar amount into a rate (dollars per month), it is divided by the time increment (DT) in the model, and multiplied by a pulse of length DT and height one so that the entire amount flows into the level of R&D funds available during the last time increment of each fiscal year. Use of the pulse function provides a multiplier of zero for all time periods of the year except the last period, when it is one, which provides a once a year appropriation of funds. The R&D spending rate is determined from the number of programs in each phase and the monthly expenditure rate calculated in each phase in the R&D sector.

```
L RDFA.K=RDFA.J+DT*(RDAR.JK-RDSR.JK)                    F38
R RDAR.KL=RDBR.K*FAR.K/DT*PULSE(1,12-DT,12)             F39
R RDSR.KL=CP.K*CCOST.K+VP.K*VCEF.K+
        DP.K*DCEF.K                                     F40
```

CCOST = Concept Cost Factor ($ per program per month)
CP = Concept Programs (programs)
DCEF = Development Cost Expenditure Factor
($ per program per month)
DP = Development Programs (programs)
FAR = Funds Appropriation Ratio (dimensionless)
RDAR = R&D Appropriation (($ per year) per DT)
RDFA = R&D Funds Available ($)
RDSR = R&D Spending Rate ($ per month)
VCEF = Validation Cost Expenditure Factor
($ per program per month)
VP = Validation Programs (programs)

Research and Development sector policies allow programs to proceed faster than the normal rate whenever excess funds are available, but prevent use of the management reserve to do this until the last quarter of the

fiscal year. When a shortage of funds occurs, however, the management reserve is used to attempt to keep the programs on schedule. The management reserve is a percentage value of the funds required for the remainder of the year, thus creating a decreasing dollar requirement for reserves as the year proceeds, with no reserve requirements during the last quarter of the year. Control over funds expenditure is accomplished by the calculation of two funds availability factors for R&D, as depicted in Figure 2.43. The R&D funds availability factor represents the actual availability of funds compared to required, while the adjusted R&D funds

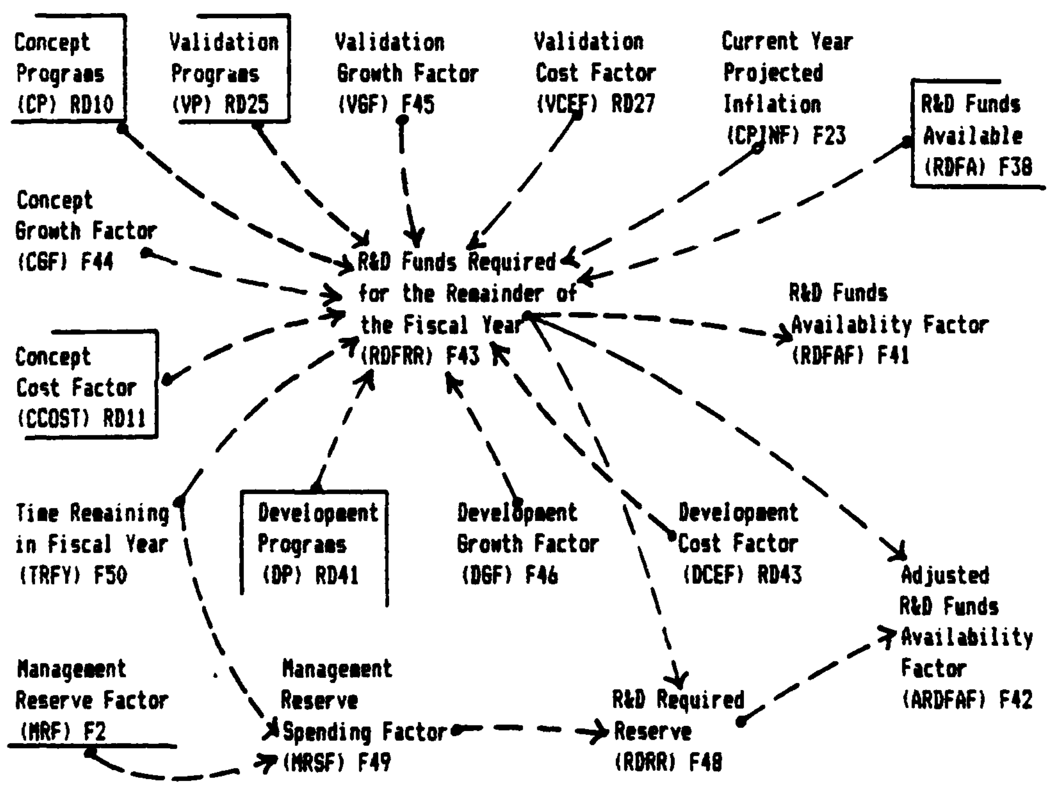


Figure 2.43 Research and Development Funds Availability Factors

availability factor represents the funds that are available after the required management reserve has been subtracted. The R&D funds required for the remainder of the year is computed from the number of programs in the three R&D phases, the desired flow rates between phases, the costs of each phase, and projected inflation for the remainder of the year.

```
A RDFAF.K=RDFA.K/RDFRR.K                                  F41
A ARDFAF.K=(RDFA.K-RDRR.K)/RDFRR.K                        F42
A RDFRR.K=((CP.K*CGF.K**(TRFY.K/2)*CCOST.K+
        VP.K*VGF.K**(TRFY.K/2)*VCOST.K+
        DP.K*DGF.K**(TRFY.K/2)*DCOST.K)*
        TRFY.K)*(1+CPINF.K)**(TRFY.K/2)                   F43
```

ARDFAF = Adjusted R&D Funds Availability Factor (dimensionless)
CCOST = Concept Cost Factor ($ per program per month)
CGF = Concept Growth Factor (factor per month)
CPINF = Current Year Projected Inflation (fraction per month)
CP = Concept Programs (programs)
DCOST = Development Cost Factor ($ per program per month)
DGF = Development Growth Factor (factor per month)
DP = Development Programs (programs)
RDFA = R&D Funds Available ($)
RDFAF = R&D Funds Availability Factor (dimensionless)
RDFRR = R&D Funds Required for Remainder of the Fiscal Year ($)
RDRR = R&D Required Reserve ($)
TRFY = Time Remaining in Fiscal Year (months)
VCOST = Validation Cost Factor ($ per program per month)
VGF = Validation Growth Factor (factor per month)
VP = Validation Programs (programs)

In the equations above, the funding requirements for the remainder of the year are projected using growth factors for the number of programs in each phase. The growth

factors are computed using the average flow rates between phases that would occur if full funding were available. Thus, the funds availability factors represent the fraction of the funding that would be required to maintain the desired flow rate.

```
A CGF.K=1+SMOOTH((NS.JK-(EVS.K+CCNX.JK))/
        CP.K,STIME)                                  F44
A VGF.K=1+SMOOTH((EVS.K-(EDSR.K+VCNX.JK))/
        VP.K,STIME)                                  F45
A DGF.K=1+SMOOTH((EDSR.K-(EPSR.K+DCNX.JK))/
        DP.K,STIME)                                  F46
```

CCNX = Concept Cancellation Rate (programs per month)
CGF = Concept Growth Factor (factor per month)
CP = Concept Programs (programs)
DCNX = Development Cancellation Rate (programs per month)
DGF = Development Growth Factor (factor per month)
DP = Development Programs (programs)
EDSR = Estimated Development Start Rate (programs per month)
EPSR = Estimated Production Start Rate (programs per month)
EVS = Estimated Validation Start Rate (programs per month)
NS = New Program Start Rate (programs per month)
STIME = Smoothing Time (months)
VCNX = Validation Cancellation Rate (programs per month)
VGF = Validation Growth Factor (factor per month)
VP = Validation Programs (programs)

The R&D reserve required is computed based upon the policy described earlier for the use of the management reserve. This is accomplished in the model by computing the management reserve spending factor, which is equal to the management reserve factor during the first three quarters and equals one during the last quarter of the fiscal year. The R&D reserve required is a constant fraction of the R&D

funds required for the remainder of the year until the last quarter.

```
A RDRR.K=RDFRR.K*(MRSF.K-1)                                F48
A MRSF.K=CLIP(MRF,1,TRFY.K,3)                              F49
```

MRF = Management Reserve Factor (dimensionless)
MRSF = Management Reserve Spending Factor (dimensionless)
RDFRR = R&D Funds Required for Remainder of the Fiscal Year ($)
RDRR = R&D Required Reserve ($)
TRFY = Time Remaining in Fiscal Year (months)

The procurement appropriation process is very similar to the R&D appropriation process. The Procurement spending rate is calculated by summing the production and modification spending, as determined from the rates of modification and production starts. Both modifications and production are costed at the time of start or obligation of cost. The funds availability factors for production are calculated in the same manner as those in R&D funding.

```
L PFA.K=PFA.J+DT*(PAR.JK-PSR.JK)                           F51
R PAR.KL=PBR.K*FAR.K/DT*PULSE(1,12-DT,12)                  F52
R PSR.KL=PCOST.K*(PRODS.JK*PECR.K+
        MODS.JK*MODCF)                                     F53
A PFAF.K=PFA.K/PFRR.K                                      F54
A APFAF.K=(PFA.K-PRR.K)/PFRR.K                             F55
A PFRR.K=((PP.K*PGF.K**(TRFY.K/2)*DROP.K*
        PTECH.K+DMODS.K*MODCF)*PCOST.K*TRFY.K*
        (1+CPINF.K)**(TRFY.K/2)                            F56
A PGF.K=1+SMOOTH((EPSR.K-PT.JK)/PP.K,STIME)                F57
A PRR.K=PFRR.K*(MRSF.K-1)                                  F58
```

APFAF = Adjusted Procurement Funds Availability Factor (dimensionless)
CPINF = Current Year projected Inflation (fraction per month)
DMODS = Desired Modification Start Rate (capability units per month)

DROP = Desired Rate of Production
(production units per month per program)
EPSR = Estimated Production Start Rate
(programs per month)
FAR = Funds Appropriation Ratio (dimensionless)
MODCF = Modification Cost Factor (dimensionless)
MODS = Modification start Rate
(capability units per month)
MRSF = Management Reserve Spending Factor
(dimensionless)
PAR = Procurement Appropriation Rate ($ per month)
PBR = Procurement Budget Request ($)
PCOST = Production Cost Factor
($ per capability unit)
PECR = Production Efficiency Cost Ratio
(dimensionless)
PFA = Procurement Funds Available ($)
PFAF = Procurement Funds Availability Factor
(dimensionless)
PFRR = Procurement Funds Required for the Remainder
of the Fiscal Year ($)
PGF = Production Growth Factor (factor per month)
PP = Production Programs (programs)
PRODS = Production Start Rate
(capability units per month)
PT = Production Termination Rate
(programs per month)
PRR = Procurement Required Reserve ($)
PSR = Procurement Spending Rate ($ per month)
PTECH = Production Technology Level
(capability units per production unit)
STIME = Smoothing Time (months)
TRFY = Time Remaining in Fiscal Year (months)

The operations and support appropriation and spending process (see Figure 2.44) differs considerably from the process described for R&D and procurement. Operations and support is the only funding category for which supplemental appropriations have been included. The supplemental appropriation is requested in January if it is needed. After request, the supplemental appropriation is delayed for six months as the Congress evaluates and acts on the request.

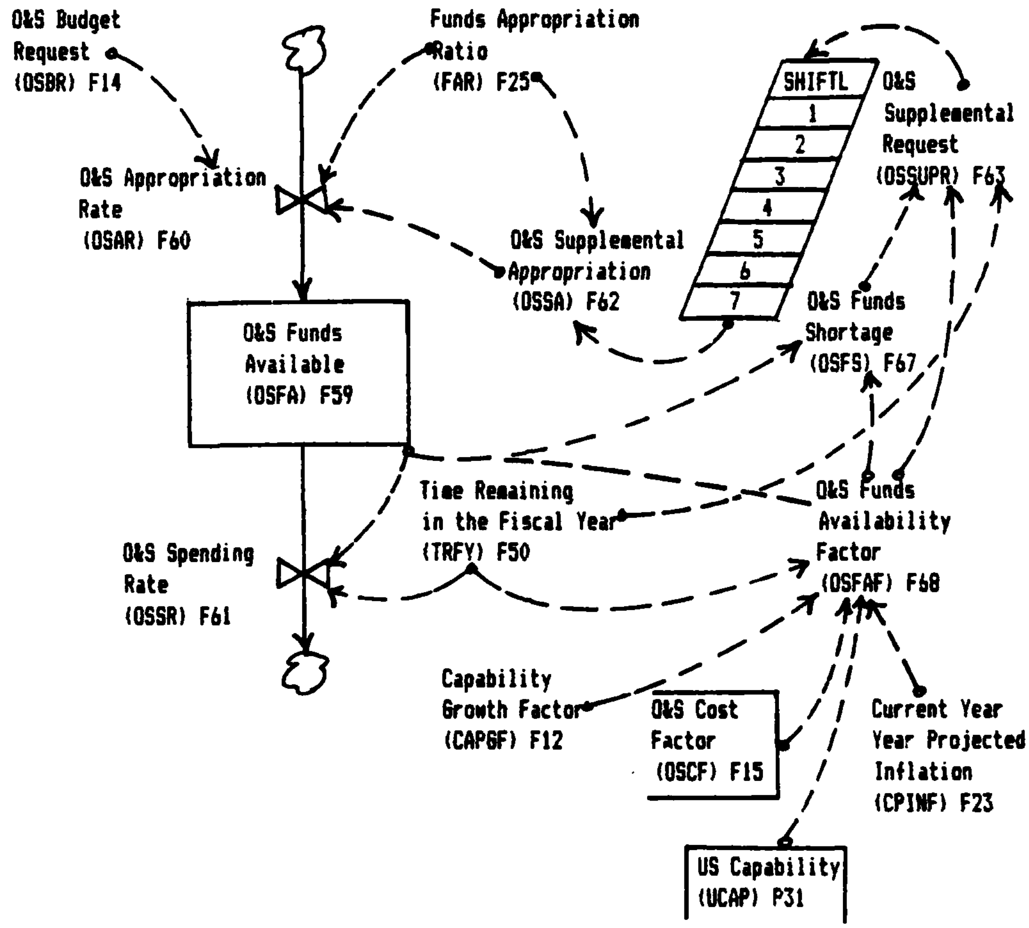


Figure 2.44 Partial Flow Diagram of
Operations and Support Appropriation and Expenditures

The required six month delay is accomplished in the model using the DYNAMO function SHIFTL. The SHIFTL function in equation F62 shifts the values of the array OSSUPR from one element to the next every month, so that the exact amount that was placed in element one in January comes out of element seven in July. The spending rate for O&S is modeled as a linear expenditure over the year. The O&S spending section is included in the model to allow the expenditure of

DoD funds not designated for acquisition. The linear spending pattern was discussed during interviews and it was agreed that it is an adequate representation for the purposes of this model.

```
L OSAF.K=OSFA.J+DT*(OSCAR.JK-OSSR.JK)                F59
R OSAR.KL=OSBR.K*FAR.K/DT*PULSE(1,12-DT,12)+
          OSSA.K                                     F60
R OSSR.KL=OSFA.K/TRFY.K                              F61
A OSSA.K=SHIFTL(OSSUPR.K,1)*FAR.K                    F62
L OSSUPR.K(1)=CLIP(0,1,OSFAF.J,.99)*OSFS.K           F63
C  M=7                                               F64
FOR I=1,M                                            F65
N OSSUPR(I)=0                                        F66
A OSFS.K=(1-OSFAF.K)*OSFA.K                          F67
A OSFAF.K=(OSFA.K+SUMV(OSSUPR.K,2,M))/
          (PCAP.K*CAPGF.K**(TRFY.K/2)*OSCF.K*
          TRFY.K*(1+CPINF.K)**(TRFY.K/2))            F68
```

CAPGF = Capability Growth Factor (factor per month)
CPINF = Current Year Projected Inflation (fraction per month)
FAR = Funds Appropriation Ratio (dimensionless)
M = Number of Time Periods Required for Processing the Supplemental Request plus One
OSCR = O&S Appropriation Rate (($ per year) per DT)
OSBR = O&S Budget Request ($)
OSCF = O&S Cost Factor ($ per capability unit per month)
OSFA = O&S Funds Available ($)
OSFAF = O&S Funds Availability Factor (dimensionless)
OSFS = O&S Funds Shortage ($)
OSSA = O&S Supplemental Appropriation ($)
OSSR = O&S Spending Rate ($ per month)
OSSUPR = O&S Supplemental Request ($)
PCAP = Potential US Capability (capability units)
TRFY = Time Remaining in Fiscal Year (months)

Financial Sector Summary. The discussion of the financial sector has introduced several key concepts. the use of funding availability to control the rate of work accomplishment was discussed, along with the process for determining the amount of funds available. The concept of

affordability introduced in the R&D sector was expanded to the budget process through a policy of requesting sufficient funds for an affordable number of R&D and production programs. The political and economic factors which control the appropriation process were also developed, as well as the policies which govern spending. The next sector to be discussed is the technology sector, which provides several important influences on progress in the R&D and production sectors.

Technology Sector

The Technology sector's primary function is to provide values for variables that will be used in research and development and production to help determine the flow and cost of programs and capability. Development of the technology sector was confined to producing the variables needed in other sectors, although the interactions found here are necessarily similar to those that would be used in a more comprehensive technology model.

Technology, as used in this model, represents the amount of capability that can be obtained from one unit of production. The technology calculation revolves around the two levels of technology that are defined in this model (see Figure 2.45), applied and available technology. The technology available is that technology that has been discovered and tested to the point that the process of applying it to production may begin. The technology applied is technology

that has been transferred from available to application in the production process. Technology is cumulative and becomes outdated as a result of comparison of the level applied to a given item of production with the level available today. It should be noted that the transfer of technology from available to applied is not a flow of technology from one to the other, but rather a result of a flow of information regarding the available technology that has yet to be applied.

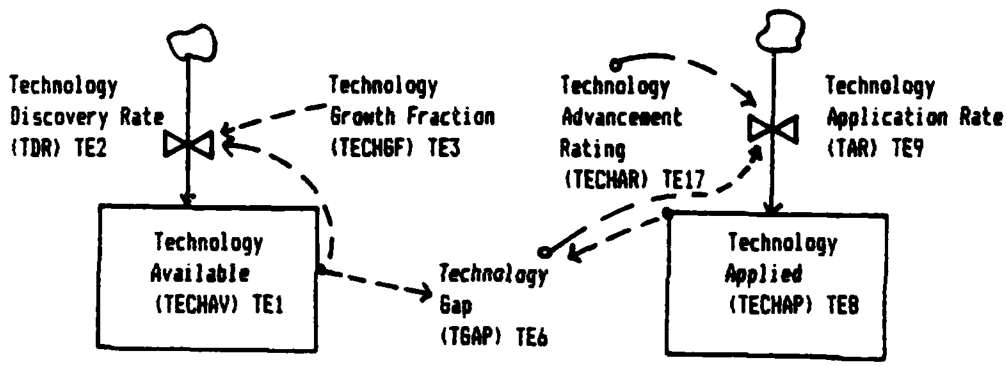


Figure 2.45
Flow Diagram of the Levels of Technology

As shown in Figure 2.45, a key driver in the growth of technology is how much of a reach for new or advanced technology is being attempted in the acquisition process. Perry, et al, (24) developed a scale of technological advance ratings and produced aggregate values for the technology advance ratings of the 1950's and 1960's of 12.2 and 8.9 respectively (24:14). Interviewees questioned on this felt the 1970's would be in the range of nine to ten. The scale of technological advance ratings shown in Figure 2.46

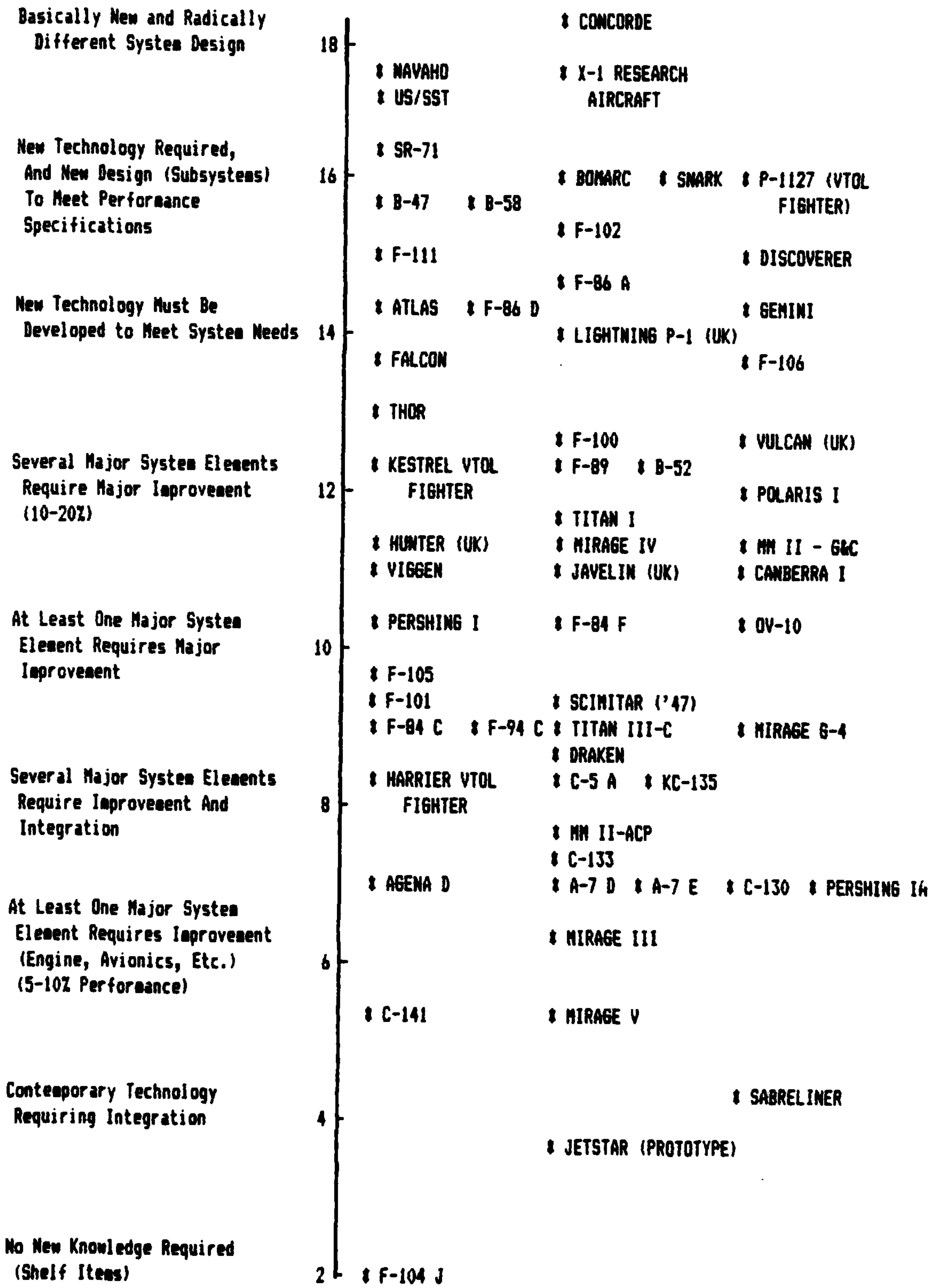


Figure 2.46 Technological Advance Ratings (24:Fig.2)

has been incorporated in the model as a policy variable that is input to the model. The description of the technology sector formulation is divided into three parts: determination of technology available, technology applied, and the effects of technology on the acquisition process.

Technology Available. The growth of technology is generally believed to follow an exponential growth pattern. That is, the rate of technology discovery is proportional to the amount of technology available at any given time. This fundamental assumption about the nature of technology growth results in the equations below for the level of technology available and the technology discovery rate.

```
L TECHAV.K=TECHAV.J+DT*TDR.JK                          TE01
R TDR.KL=TECHAV.K*TECHGF.K                             TE02

TDR = Technology Discovery Rate
        ((capability per production unit) per month)
TECHAV = Technology Available
        (capability per production unit)
TECHGF = Technology Growth Fraction
        (fraction  per month)
```

The technology available for weapon system development is a result of research and testing by both government and civilian organizations. Mercer (21:88) describes a growth pattern for technology with the growth occurring in generations. A higher level of growth occurs when the gap between available and applied is smaller and then the growth "levels off as the limitations of its tools, techniques, and devices are approached [21:88-89]." In consideration of

this and the fact that the amount of government and civilian research will be affected by the level of government funding available, the fractional growth rate of technology available was developed. The technology growth fraction was found to vary from its normal value depending upon the gap between available and applied technology, and the level of funding that the DoD is receiving from the Congress (see Figure 2.46). The normal growth fraction is computed by solving for the fractional rate which would be required, when compounded, to achieve a doubling of technology available in the time between generations.

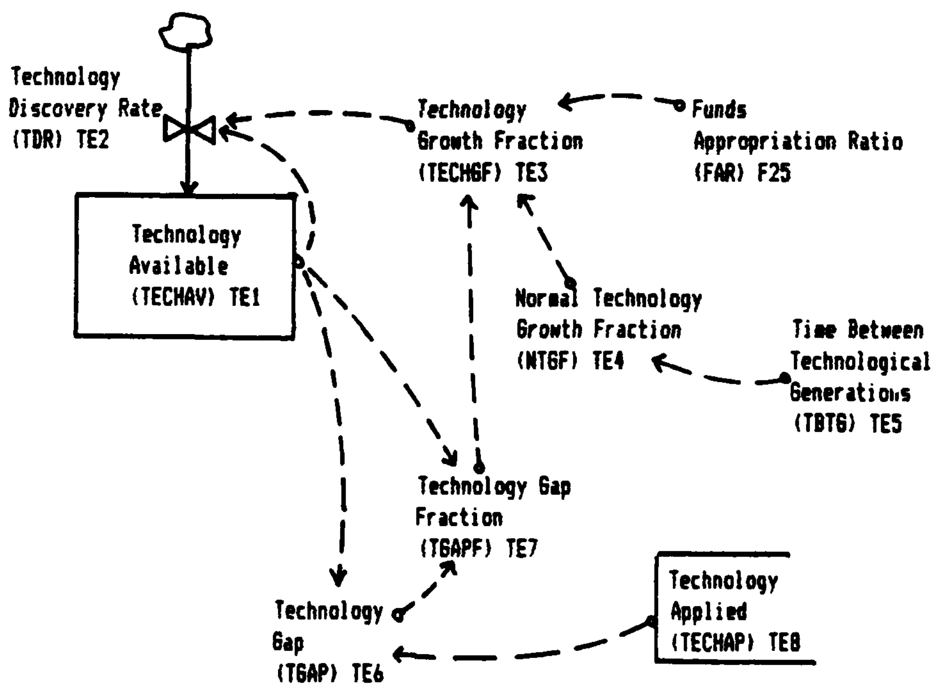


Figure 2.47
Technology Discovery Flow Diagram

```
A TECHGF.K=NTGF.K*FAR.K*(1-TGAPF.K)**2          TE03
A NTGF.K=(2**(1/TBTG.K))-1                      TE04
A TBTG.K=96                                     TE05
A TGAP.K=TECHAV.K-TECHAP.K                      TE06
A TGAPF.K=TGAP.K/TECHAV.K                       TE07
```

FAR = Funds Appropriation Ratio (dimensionless)
NTGF = Normal Technology Growth Fraction (fraction per month)
TBTG = Time Between Technology Generations (months)
TECHAP = Level of Applied Technology (capability per production unit)
TECHAV = Level of Available Technology (capability per production unit)
TGAP = Gap Between Available and Applied Technology (capability per production unit)
TGAPF = Normalized Technology Gap (dimensionless)

Applied Technology. Applied technology grows as a function of the difference between available and applied technology as shown in Figure 2.45. The technology application rate is dependent on the assumption that as higher technology advancement ratings are attempted, the application rate would be accelerated. No specific data was found on this application rate, so the table of transfer times shown in equation TE10 was developed from the assumption that at the start of the model run, for a technological advance rating of ten, the transfer time and development duration would be approximately equal. This means that the technology available at the start of a full scale development program is applied at the completion of that program. Higher technological advance ratings result in the application of technology that had not been completely developed and tested at the beginning of full scale development. For lower technological advance ratings, the technology applied

is older and was discovered sometime before the start of full scale development.

```
L TECHAP.K=TECHAP.J+DT*TAR.JK                          TE08
R TAR.KL=TGAP.K/TABLE(TTAT,TECHAR.K,0,20,2)            TE09
T TTAT=72,60,48,36,30,24,21,18,16,14,12                TE10

TAR = Technology Application Rate
       ((capability per production unit) per month)
TECHAP = Level of Applied Technology
       (capability per production unit)
TECHAR = Technology Advancement Rating
       (dimensionless)
TGAP = Gap Between Applied and Available Technology
       (capability per production unit)
TTAT = Table of Technology Application Times (months)
```

Effects of Technology. The effects of technology are felt in the acquisition and modification of weapon systems in several ways. First, the interviews support the conclusion that the advance of technology generally creates more complex weapon systems that cost more to develop and test, as well as taking longer to solve the problems inherent in transitioning from design to production. Second, discussions of the technological advancement ratings during the interviews pointed to a relationship between the time required to acquire a weapon system and the technology advance being attempted. Procurement of systems in the technological advance rating range of eighteen to twenty was estimated to take approximately two to three times as long as programs in the six to eight technology advance range, depending on the urgency and commitment to a particular project. A third effect of technology is the level of

technology that is applied to production. This level determines the amount of capability obtained in each production unit. The final effect of technology is the propensity to modify weapon systems as the technology becomes available to make them more capable and to extend their useful lifetime. This last effect is accomplished in the production sector using the technology available as its input. It requires no special calculations in the technology sector. The other three are discussed in detail in the next three paragraphs.

The increasing complexity of weapons systems that results from higher levels of technology being applied was modeled as the weapon system complexity factor (WSCF) that is used in the R&D sector to increase the base cost of validation and development (equations RD29 and RD45) and in development to increase the base time required (equation RD38). Evaluation of several alternative formulations for the weapons system complexity factor led to using the base ten logarithm of the technology applied. This formulation achieves a factor that grows when technology does, but is restrained and more moderate than the level of technology.

```
A WSCF.K=1+LOGN(TECHAP.K)/LOGN(10)                    TE11

TECHAP = Level of Applied Technology
         (capability per production unit)
WSCF = Weapon System Complexity Factor
         (dimensionless)
```

The effect of the technological advancement rating on the duration of programs was incorporated into the model by

determining a target duration for the validation phase based upon the time required for the desired amount of technology growth, as depicted in Figure 2.48. The additional time required for higher advance ratings was incorporated into the validation phase since the nature of validation is risk reduction and technology testing.

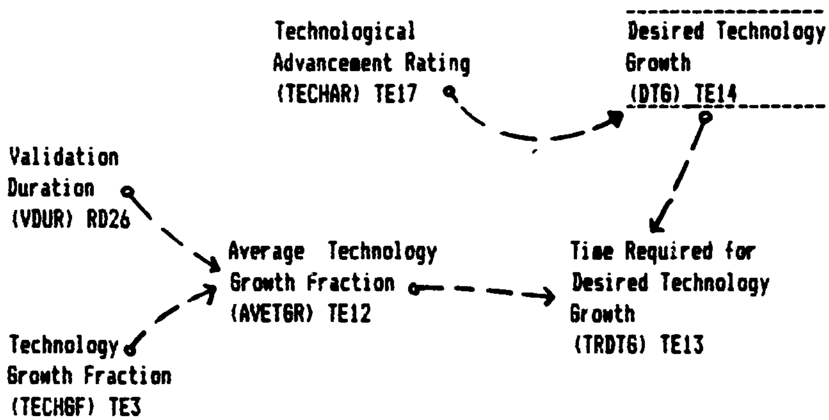


Figure 2.48 Flow Diagram of the Time Required for the Desired Technology Growth

```
A AVETGR.K=SMOOTH(TECHGF.K,VDUR.K)                    TE12
A TRDTG.K=LOGN(DTG.K)/AVETGR.K                        TE13
A DTG.K=TABLE(TDTG,TECHAR.K,0,20,2)                   TE14
T  TDTG=1.0,1.0,1.0,1.05,1.1,1.2,1.5,
        1.65,1.7,1.75,1.8                             TE15
```

AVETGR = Average Technology Available Growth Fraction (fraction per month)
DTG = Technology Growth Factor for the Desired Technology Advance Rating (factor)
TDTG = Table of Desired Technology Growth Factors
TECHAR = Technology Adva ce Rating (dimensionless)
TECHGF = Tachnology Growth Fraction (fraction per month)
TRDTG = Time Required for Desired Technology Growth (month)

The technology being applied to production is the average level of applied technology determined over one-half of the duration of a program's production. The factor of one-half is used to allow for updates or modifications that are made to the weapon system during production as the technology is both better developed and updated technology introduced.

A PTECH.K=SMOOTH(TECHAP.K,(PDUR.K/2)) TE16

PDUR = Production Duration (months)
PTECH = Production Technology
(capability per production unit)
TECHAP = Level of Available Technology
(capability per production unit)

Technology Sector Summary. The concepts introduced in the technology sector include: the measurement of technology, the levels of technology available and applied, the growth of technology in generations, the effect of the technological advance rating on the growth of technology, and the effects of technology on the acquisition process. The last sector to be discussed is the threat sector.

The Threat Sector

The primary function of the threat sector is to determine the threat which drives the other sectors of the model through the pressure for research and development, the DoD pressure for acquisition, and the Congressional presure for acquisition. The pressure for R&D results from a

comparison of long-term projections of US and enemy capability, while the DoD and Congressional pressures for acquisition result from comparing near-term capabilities. For modeling and analysis the enemy was assumed to be a single nation, specifically, the Soviet Union.

Comparison of US and enemy capability in the Threat Sector uses several variables from other sectors. US capability from the production sector is projected into the future using the rates of modification and obsolescence of US forces and the number of programs in each phase of the acquisition process together with the durations of the four phases and the amount of capability expected from each program. Enemy spending is converted to capability using US R&D and production cost factors.

In order to compare US and enemy capabilities in the aggregate, a surrogate measure was used. Results of research (1:7; 18:15; 35:2; 36:II-4) and interviews indicate that use of US and Soviet military investment (RDT&E and procurement), accumulated over the lifetime of the hardware, is an effective measure of comparative capability for modelling purposes. Enemy capability is therefore a function of the enemy expenditure for military investment, in dollars, and the amount of capability that could be purchased with those dollars. The enemy expenditure is determined as a fraction of the enemy GNP, with the fraction varying as a function of the threat perceived by the enemy. The

discussion of the threat sector formulation is divided into three parts: enemy capability, pressure for research and development, and pressure for acquisition.

Enemy Capability. Computation of enemy defense spending first requires calculation of enemy gross national product (GNP). The enemy GNP, as shown in Figure 2.49, grows by some fraction each year, representing real growth plus inflation. The enemy GNP is measured in current US dollars to facilitate comparison of military investments. A GNP real growth rate of .25 percent per month (approximately 3% per year) was used during development of the model. Equation TH3 can be changed to reflect any desired or predicted rate the modeler desires.

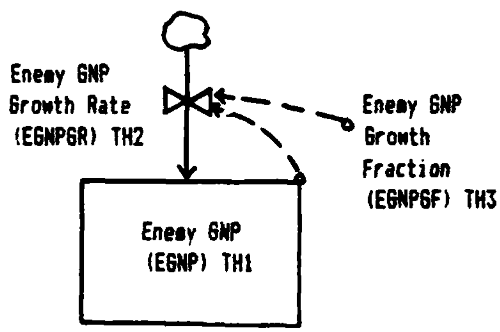


Figure 2.49 Enemy GNP Flow Diagram

```
L EGNP.K=EGNP.J+DT*EGNPGR.JK                    TH1
R EGNPGR.KL=EGNP.K*EGNPGF.K                     TH2
A EGNPGF.K=.0025+INF.K                          TH3
```

EGNP = Enemy Gross National Product ($ per year)
EGNPGF = Enemy GNP Growth Fraction
(fraction per month)
EGNPGR = Enemy GNP Growth Rate ($ per month)
INF = Inflation Fraction (fraction per month)

The fraction of GNP that the enemy spends on military investment is modeled as a function of the threat perceived by the enemy after evaluating his own capability and intelligence forecast of US capability, as depicted in Figure 2.50. Lower and upper limits on enemy GNP spending fraction reflect the enemy desire for world domination, and the political and economic reality faced by the enemy leadership. The enemy capability adjustment time (EADJT), in equation TH7, reflects the length of time the enemy is willing to take to gain the desired level of superiority

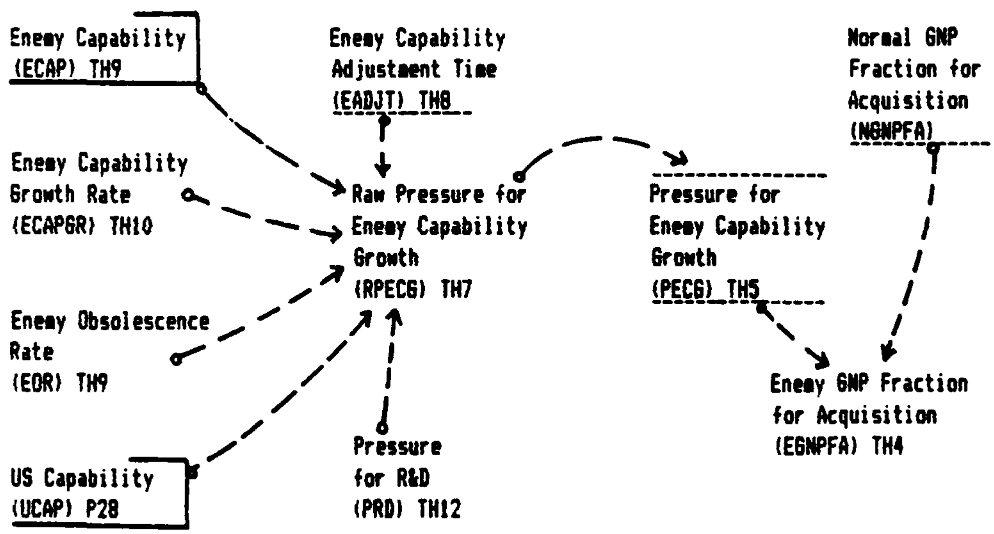


Figure 2.50 Enemy GNP Fraction
for Acquisition Determination

over the US. The enemy intelligence delay time is the age of the information used by the enemy for forecasting the US capability. It should be noted that the enemy forecast of US capability is based upon US intentions, as measured in the pressure for R&D, rather than using an extrapolation of

actual US production, modification, and obsolescence rates. This choice of formulation was made because the openness of the US Government allows information about DoD intentions to acquire new capability to be known by the enemy. As will be seen later, however, the US must rely on projecting past trends in Soviet behavior, because their intentions are not made public. The use of a constant "normal" GNP fraction for acquisition was based upon the information that Soviet defense spending is expected to remain fairly stable as a fraction of GNP in the foreseeable future (1).

```
A EGNPFA.K=NGNPFA*PECG.K                                 TH4
A PECG.K=TABHL(TEPCG,RPECG.K,1.0,1.2,,2)                 TH5
T  TPECG=1.0,1.2                                         TH6
A RPECG.K=(DLINF3(UCAP.K,EINT)-(ECAPGR.JK-
     EOR.JK)*EADJT)*DLINF3(PRD.K,EINT)/ECAP.K            TH7
```

EADJT = Enemy Capability Adjustment Time (months)
ECAP = Enemy Capability (capability)
ECAPGR = Enemy Capability Growth Rate (capability per month)
EGNPFA = Enemy GNP Fraction for Acquisition (dimensionless)
EINT = Enemy Intelligence Delay Time (months)
NGNPFA = "Normal" GNP Fraction for Acquisition (dimensionless)
PECG = Pressure for Enemy Capability Growth (dimensionless)
PRD = Pressure for R&D (dimensionless)
RPECG = Raw Pressure for Enemy Capability Growth (dimensionless)

TPECG = Table of Pressure for Enemy Capability Growth (dimensionless)
UCAP = US Capability (capability)

The growth of enemy capability is calculated using the GNP fraction and enemy GNP as determined above, to purchase capability, as shown in Figure 2.51. The enemy

cost per capability unit is determined from what capability is costing the US. US prices for capability are used because historical values for Soviet military spending, which were used in the development of enemy spending for acquisition, were determined by valuing what the Soviets purchased at the price the US would have to pay (22:1).

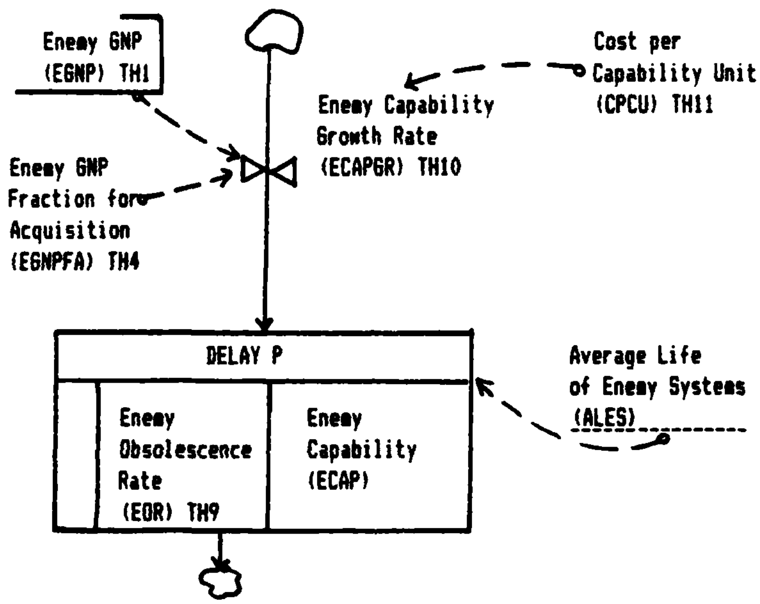


Figure 2.51
Enemy Capability Flow Diagram

```
R EOR.KL=DELAYP(ECAPGR.JK,ALES,ECAP.K)                    TH9
R ECAPGR.KL=EGNP.K*EGNPFA.K/CPCU.K/12                     TH10
A CPCU.K=(CCOST.K*CDUR.K+VCOST.K*EVDUR.K+
        DCOST.K*ESDDUR.K)/CPP+PCOST.K                     TH11
```

CCOST = Concept Cost Factor
($ per program per month)
CDUR = Concept Duration (months)
CPCU = Cost Per Capability Unit
($ per capability unit)
CPP = Capability Per Program
(capability units per program)
DCOST = Development Cost ($ per program per month)
ECAP = Enemy Capability (capability units)

ECAPGR = Enemy Capability Growth Rate
(capability units per month)
EGNP = Enemy GNP ($ per year)
EGNPFA = Enemy GNP Fraction for acquisition
(dimensionless)
EOR = Enemy Obsolescence Rate
(capability units per month)
ESDDUR = Estimated Development Duration (months)
EVDUR = Estimated Validation Duration (months)
VCOST = Validation Cost ($ per program per month)

The enemy capability is compared to US capability in the calculation of several pressures used to control US acquisition.

Pressure for Research and Development. The pressure for research and development, used in the determination of program starts and flow through the acquisition system, is calculated from the long term threat projection and the need to maintain the defense industrial base, as shown in Figure 2.52. The threat projection, or raw pressure for R&D, is computed by comparing the projected gap between the US and

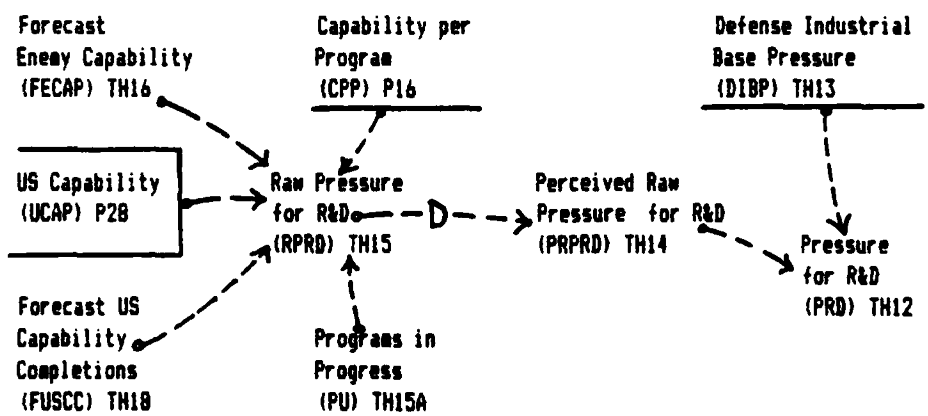


Figure 2.52
Pressure for Research and Development Flow Diagram

enemy capabilities and the amount of capability that is expected from the programs now in progress. The result measures the factor by which the US needs to increase the number of programs in order to have an equal capability and the end of the planning horizon. This information is delayed by the amount of time required for the DoD to perceive and react to a change in the relative trend in capability. In the interviews, this time was believed to be about one year. The defense industrial base pressure recognizes the need to maintain the defense industrial base and political pressure applied by defense contractors, by providing a floor below which the pressure for R&D will not fall. Even if the threat were very small, the US would not suddenly stop acquiring new weapons systems, but would instead gradually reduce the number of programs while continuing to keep the industrial base alive. In contrast to the pressure for enemy capability growth discussed previously, there is no upper limit on the pressure for R&D. This is because the US political and economic realities are recognized in the financial sector, making it unnecessary to invoke an arbitrary limit.

```
A PRD.K=MAX(DIBP,PRPRD.K)                             TH12
C DIBP=0.9                                            TH13
A PRPRD.K=DLINF3(RPRD.K,TDPP)                         TH14
A RPRD.K=1+((FECAP.K-UCAP.K-FUSCC.K)/
        (CPP*PU.K))                                   TH15
```

CPP = Capability Per Program (capability per program)
DIBP = Defense Industrial Base Pressure
(dimensionless)

FECAP = Forecast Enemy Capability (capability units)
FUSCC = Forecast US Capability Completions (capability units)
PRD = Pressure for R&D (dimensionless)
PRPRD = Perceived Pressure for R&D (dimensionless)
PU = Programs in Progress (programs)
RPRD = Raw Pressure for R&D (dimensionless)
TDPP = Time for DoD to Perceive Pressure (months)
UCAP = US Capability (capability units)

The capability forecasts used in the above calculations for the pressure for R&D are computed by projecting the US and enemy capability into the future by a planning horizon that is equal to the total time required for a program to progress from milestone zero to the completion of the production phase. The length of the planning horizon was evaluated during testing of the threat sector. Originally modeled as a constant, the planning horizon was found to be a parameter to which the sector was especially sensitive. A short planning horizon (36 months) led to the failure of the model to recognize an unfavorable trend in relative capability until the US was irreversibly behind. On the other hand, a long planning horizon (twice the length of the acquisition cycle) caused the model to reduce the number of new starts too early to allow the US to completely catch up. Since US policy is to seek approximate parity with our potential adversaries, the system should seek that state as a goal. A planning horizon equal to the time required for a program to progress through the entire acquisition process proved to give just that behavior and was therefore used. This choice is also appropriate from the

viewpoint of mission analysis, since the planning horizon should be the period of time over which the results of the planning process (new programs) will have an effect on the relative capability of the US and the Soviet Union.

The enemy capability forecast is computed by assuming that the current fractional rate of growth in enemy capability will continue over the planning horizon. The forecast of US capability completions is based upon the acquisition programs in existence and rates of modification and obsolescence during the planning horizon. All information regarding the enemy is delayed by the time required for the intelligence community to obtain the information. It was ascertained in the interviews that six months is a reasonable value of the intelligence delay time.

```
A FECAP.K=DLINF3(ECAP.K,UINT)*ECAPGF.K**PF          TH16
A ECAPGF.K=(DLINF3(ECAPGR.JK,UINT)-
        DLINF3(EOR.JK,UINT))/
        DLINF3(ECAP.K,UINT)+1                       TH17
A FUSCC.K=(CP.K+VP.K+DP.K+PP.K)*CPP+
        (MODC.JK-UOR.JK)*PH.K                       TH18
A PH.K=CDUR+EVDUR.K+EDDUR.K+EPD.K                   TH19
```

CDUR = Concept Duration (months)
CP = Concept Programs (programs)
CPP = Capability per Program (capability per program)
DP = Development Programs (programs)
ECAP = Enemy Capability (capability)
ECAPGF = Enemy Capability Growth Factor
(factor per month)
ECAPGR = Enemy Capability Growth Rate
(capability units per month)
EDDUR = Estimated Development Duration (months)
EOR = Enemy Obsolescence Rate (capability per month)
EPD = Estimated Production Duration (months)
EVDUR = Estimated Validation Duration (months)
FECAP = Forecast Enemy Capability (capability units)

FUSCC = Forecast US Capability Completions
(capability units)
MODC = Modification Completion Rate
(capability units per month)
PH = Planning Horizon (months)
PP = production Programs (programs)
UINT = US Intelligence Delay (months)
UOR = US Obsolescence Rate (capability per month)
VP = Validation Programs (programs)

Pressure for Acquisition. The other two key variables computed by the threat Sector are the DoD pressure for acquisition and the Congressional pressure for acquisition. The DoD pressure for acquisition is used in the production affordability test in the R&D Sector and in determining the rate of modification of forces in the production sector. The Congressional pressure for acquisition is combined with other political and economic factors in the financial sector to determine the fraction of the DoD budget appropriated by Congress. As shown in Figure 2.53, the difference between the two pressures is the amount of time or delay in perceiving the changes in relative capability between the US and the enemy. The amount of time required for the DoD and Congress to perceive a change in the threat was not well established in the interviews. The values used were considered minimum times for the DoD or Congress to perceive a gradually changing threat. It was noted that reaction to a sudden, well publicized event could be reacted to much faster. The pressure for acquisition combines a comparison of the present US and enemy capability with the defense industrial base pressure defined above.

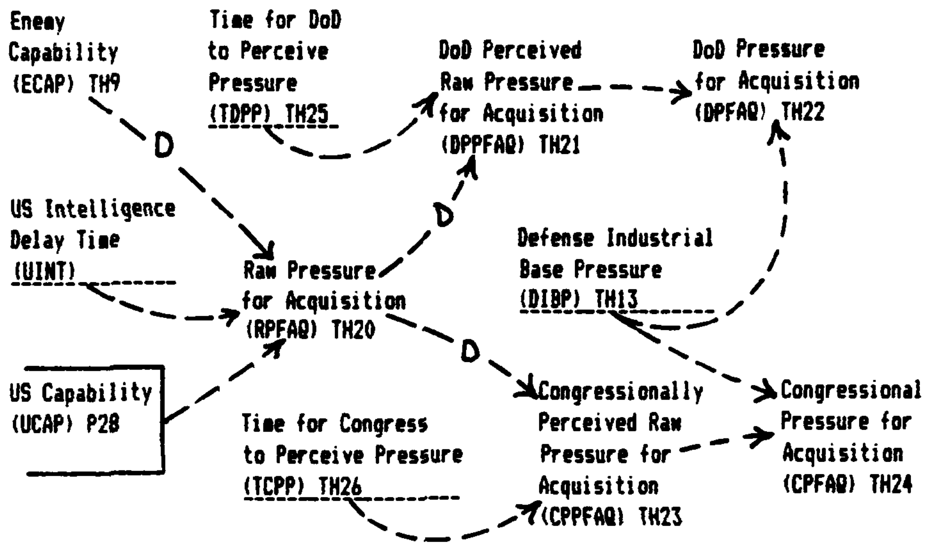


Figure 2.53
Pressure for Acquisition Flow Diagram

```
A RPFAQ.K=DLINF3(ECAP.K,UINT)/UCAP.K                TH20
A DPPFAQ.K=DLINF3(RPFAQ.K,TDPP)                     TH21
A DPFAQ.K=MAX(DIBP,DPPFAQ.K)                        TH22
A CPPFAQ.K=DLINF3(RPFAQ.K,TCPP)                     TH23
A CPFAQ.K=MAX(DIBP,CPPFAQ.K)                        TH24
C TDPP=12                                           TH25
C TCPP=24                                           TH26
```

CPFAQ = Congressional Pressure for Acquisition (dimensionless)
CPPFAQ = Congressionally Perceived Raw Pressure for Acquisition (dimensionless)
DIBP = Defense Industrial Base Pressure (dimensionless)
DPFAQ = DoD Pressure for Acquisition (dimensionless)
DPPFAQ = DoD Perceived Raw Pressure for Acquisition (dimensionless)
ECAP = Enemy Capability (capability units)
RPFAQ = Raw Pressure for Acquisition (dimensionless)
TCPP = Time for Congress to Perceive Pressure (months)
TDPP = Time for DoD to Perceive Pressure (months)
UCAP = US Capability (capability units)
UNIT = US Intelligence Delay Time (months)

Threat Sector Summary. In the discussion of the threat sector, several important concepts were developed. The use of US and Soviet military investment spending as a surrogate measure for capability was developed, along with the concepts of three pressures which drive the other sectors of the model. These three are the pressure for research and development, the DoD pressure for acquisition, and the Congressional pressure for acquisition. The presentation of model formulation is now complete.

Chapter Summary

Chapter Two has presented the conceptualization of the DoD acquisition system model, followed by discussion of the sectorization of the model into five sectors. The formulation of each of the sectors was also presented. Chapter Three presents the model testing which was performed to establish the validity of the model for the purpose of the study.

CHAPTER 3

MODEL TESTING AND VALIDATION

Introduction

The model described in the preceding chapter was subjected to numerous tests throughout its development. According to Forrester and Senge, testing is

> the comparison of a model to empirical reality for the purpose of corroborating or refuting the model. It is important to realize that the word "empirical" means "derived from or guided by experience or experiment" (Random House Unabridged Dictionary of the English Language). Hence empirical information for testing a model includes information in many forms other than numerical statistics. In system dynamics models, model structure can be compared directly to descriptive knowledge of real-system structure; and model behavior can be compared to observed real-system behavior [13:210].

The purpose of this extensive testing, both of model sectors and the complete model, was validation of the model, which is defined as

> establishing confidence in the soundness and usefulness of a model. Validation begins as the model builder accumulates confidence that a model behaves plausibly and generates problem symptoms or modes of behavior seen in the real system. Validation then extends to include persons not directly involved in constructing the model. Thus, validation includes the communication process in which the model builder (or someone else presenting a model) must communicate the bases for confidence in the model to a target audience. Unless the modeler's confidence in a model can be transferred, the potential of a model to enhance understanding and lead to a more effective policies will not be realized [13:210].

This chapter, therefore, extends the validation process to its later stages by reporting the tests which have led to the model builders' confidence that the model is sound and useful for understanding the DoD acquisition system, and for evaluating DoD acquisition policy.

Forrester and Senge (13:227) describe an array of tests (Table 3.1) which can be applied to system dynamics models for building confidence. All of the "core tests" and several of the other tests identified in Table 3.1 were accomplished on this model. The tests of model structure were conducted continuously during model conceptualization and formulation. The details of how the structure of the model corresponds to the DoD acquisition system were presented in Chapter 2 and will not be repeated. Instead, a brief description of the structural tests is presented, followed by a more detailed description of the results of the tests of model behavior. The tests of policy structure are addressed in Chapter 4 along with the policy analysis that was conducted. For a detailed description of the tests themselves, the reader is referred to Forrester and Senge (13).

Tests of Model Structure

Tests of model structure consider the structure and parameters of the model without considering the relationship between structure and behavior. The next several paragraphs describe the tests of model structure that were conducted.

Tests of Model Structure

a	1. Structural Verification
a	2. Parameter Verification
a	3. Extreme Conditions
a	4. Boundary Adequacy
a	5. Dimensional Consistency

Tests of Model Behavior

a	1. Behavior Reproduction
	2. Behavior Prediction
a	3. Behavior Anomaly
	4. Family Member
	5. Surprise Behavior
	6. Extreme Policy
	7. Boundary Adequacy
a	8. Behavior Sensitivity

Tests of Policy Implications

	1. System Improvement
a	2. Changed Behavior Prediction
	3. Boundary Adequacy
a	4. Policy Sensitivity

Table 3.1 Confidence Building Tests
a = Core Tests
(13:Table 1)

Structure-Verification Test. The structure-verification test consists of comparing the model structure with the structure of the real system (13:212). This was one purpose of the interviews: to verify (or discredit) the model structure as it existed at that time. The first round of interviews resulted in considerable change to the initial conceptualization of the model, while generally supporting the basic approach. During the second round of interviews, information was gathered which generally supported the model structure as it existed then, but still required several

changes to incorporate important structural elements that the model had not previously included. Elements that were added to the model after the second round of interviews included the ability of the R&D and production processes to be accelerated by additional money; penalty costs for R&D programs whose schedules change; the effects of the push for new technology on the duration and cost of R&D and on the technology growth rate; the concept of management reserve; and the process of modifying existing weapon systems as an alternative or complement to acquisition of new systems. After making these changes, the model structure accurately reflects existing knowledge and understandings of the acquisition system structure at the policy level.

Parameter-Verification Test. This test involves comparing parameters (constants) in the model to knowledge of the real system to determine if the model parameters match numerically and conceptually with the real system (13:213). This test was accomplished through both literature research and the interview process. All of the parameters in the model have corresponding elements in the real acquisition system. The key question then, is whether the numerical values of the model parameters are reasonably close to their real world counterparts. For parameters whose real world counterparts can be readily measured, actual values were obtained from literature research or interviews. The values of other, less readily measured,

parameters were estimated. In the case of table functions, which are in fact sets of several parameters, Graham (17:128-130) suggests that one estimate the value and slope of the function at the extremes and the normal value, and then connect these known values and slopes with a smooth curve. As discussed in Chapter Two, this method was followed for several table functions in the model, including the tables for the GNP, Fiscal Policy, and Threat Pressures, the Pressure for Non-Defense Funds, and the Technology Application Time. Alternative plausible shapes of these table functions were tested, and the model behavior was found to be insensitive to the exact values in the table functions. Certain of the parameters, most notably the Modification Technology Gap Fraction and the Normal Force Modification Time, were estimated using another of Graham's techniques (17:136-138). The parameters were tested over a broad range of possible values, with the combination of values for which the model behavior most closely resembled real system behavior selected for use in the model. In this specific case, values were chosen such that the number of modifications generated by the model produced a ratio between production and spending modification that was roughly equal to the ratio in the FY83 Aircraft Procurement budget request (16).

Extreme-Conditions Test. The extreme-conditions test (13:213-214) consists of examining each policy (rate equa-

tion) in the model, tracing it back to the levels on which the policy depends, and considering the implications of imaginary maximum and minimum values of each of the levels and combinations of levels to determine if the result is plausible. For example, the O&S spending rate is determined by the following equation:

R OSSR.KL=OSFA.K/TRFY.K

OSFA = O&S Funds Available ($)
OSSR = O&S Spending Rate ($ per month)
TRFY = Time Remaining in the Fiscal Year (months)

The O&S funds available can have any value from zero to infinity, while the time remaining in the fiscal year can range from twelve months down to the time increment (DT) of the model. Whatever amount of funds are available will therefore be spent by the end of the fiscal year, as was intended in the formulation of this equation, and the equation passes the extreme-conditions test. This test was conducted in similar, but often much more complicated, manner for each rate equation in the model.

Boundary-Adequacy (Structure) Test. The boundary-adequacy (structure) test (13:214-215) asks whether the model aggregation is appropriate and if the model includes all of the structure relevant to the model's purpose. The test cannot be conducted independent of the purpose of the model, since for different purposes, additional structure would be added to the model without limit. The purpose of this research was to provide a policy model of the DoD

acquisition system that could be used to evaluate the effects of DoD level policy changes on the acquisition system. The model, therefore, was designed at a very high level of aggregation to capture the DoD view of the acquisition system. Lower levels of aggregation were used only where major concepts could not be captured at a higher level of aggregation.

For the expressed purpose of evaluating the effects of DoD policy on the behavior of the acquisition system, the model is believed by the researchers, based upon the information gained through literature research and the interviews, to contain adequate structure at the proper level of aggregation. Further, the model was intentionally designed with potential for expansion of the model boundary into areas that cannot be addressed with the present structure.

Dimensional-Consistency Test. The dimensional-consistency test (13:215-216) consists of verifying that the dimensions on the left-hand side of each equation in the model match the dimensions of the right-hand side. This test was performed and passed on each equation of the model during formulation of equations.

Tests of Model Behavior

Several tests of model behavior were used to evaluate the adequacy of the model structure by analyzing the behavior generated by the model. Of the behavior tests listed

in Table 3.1, the behavior-reproduction, behavior-anomaly, surprise-behavior, extreme-policy, and behavior-sensitivity test were performed. This section briefly describes each of these tests and presents examples of the results which were obtained when applying the tests to the model.

Behavior-Reproduction Tests. Behavior-reproduction tests examine how well the model behavior matches observed real-system behavior. Behavior-reproduction tests include symptom-generation, frequency-generation and relative-phasing, multiple-mode, and behavior-characteristic tests (13:217-219). Two of these test types were applied to the model: symptom-generation and multiple-mode, with emphasis on the symptom-generation test.

The symptom-generation test examines whether the model can generate the problem symptoms which motivated its construction. Also, "unless one can show how the internal policies and structure cause the symptoms, one is in a poor position to alter those causes [13:217]." Thus, the cause and effect relationships that generate the symptoms must be common to the model and the real system. Three key symptoms which the acquisition system has exhibited over the last two decades motivated this modeling effort: (1) a steady increase in the cost and time required for the DoD to acquire weapon systems (36:I-4), (2) a steadily worsening situation in the comparison between US and Soviet military capability (36:II-5), and (3) a growing technological obso-

lescence of US weapons systems across a broad range of mission areas (36:I-4,I-29). In order to test whether the model recreates these symptoms, the model was initialized to simulate the time period beginning in 1970, when the US was approximately 25 percent ahead of the Soviet Union in cumulative military investment (36:II-8), which is the measure of capability in the model. The next three paragraphs discuss the resulting behavior of the key variables identified above.

To observe the behavior of the cost and time required to acquire weapon systems, two variables were defined for model output: program cost and acquisition cycle length. Program cost was defined as the average total cost of a program from start through the completion of production. Since each program in the model provides a fixed amount of capability, the comparison of the cost of a 1980 program to that of a 1970 program is much more straight forward than such a comparison would be in the real system. The acquisition cycle length was defined as the time required for a program to progress from start through delivery of the first production item. As shown in Figure 3.1, the model operation resulted in the acquisition cycle length increasing steadily from 1970 to the middle of the 1980s, while program cost continued to increase until about 1990. Cost and schedule growth are closely related to one another in both the real system and the model, with growth in the areas of

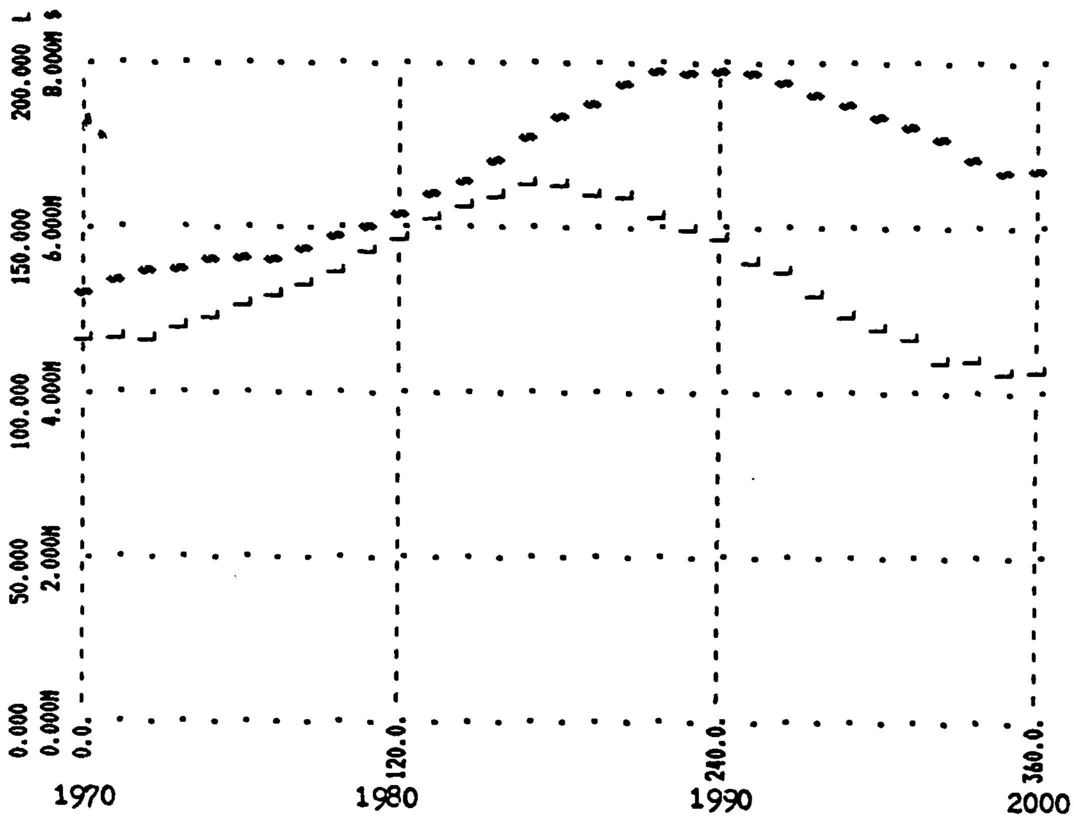


Figure 3.1
Model Output of Program Cost ($)
and Acquisition Cycle Length (L)

cost and schedule each contributing to growth in the other area. The model contains two basic mechanisms which cause this growth. The first mechanism arises from the fact that the DoD almost never gets all of the requested funding from the Congress. The resulting shortage of R&D and procurement funds causes programs to be stretched. This program stretchout, while alleviating the short term funding problem, results in a larger total program cost. This larger total program cost feeds back into itself by increasing the budget request in the succeeding years,

resulting in larger budget cuts by the Congress, which results in another funding shortage. The cycle thus repeats itself in a positive feedback loop, as depicted in Figure 3.2. The second mechanism for cost and schedule growth

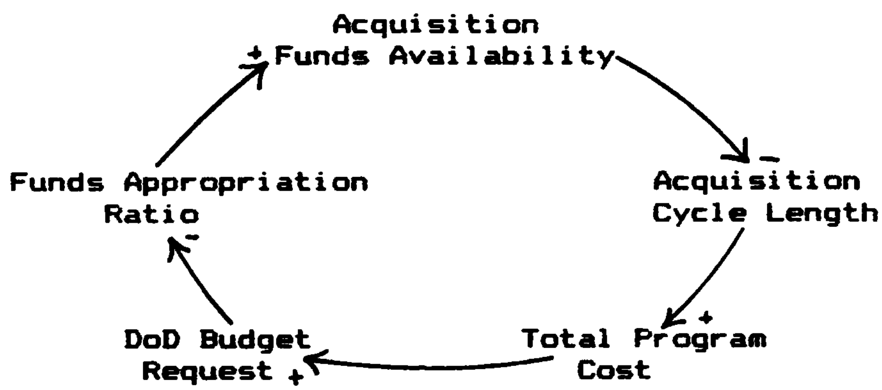


Figure 3.2 Cost and Schedule
Growth Partial Causal Diagram

arises from the longer-term affordability considerations and is more complex. At the beginning of the model run, the US was significantly ahead of the Soviet Union in capability. The projection of the long-term threat, however, had already begun to forecast a US deficiency. As a result, the model began increasing the rate of new starts and the affordability of the three phases of R&D early in the decade, while the low short-term threat kept the production affordability low. This resulted in a backlog of programs in R&D, causing the duration to stretch. This growing backlog of programs caused the long-term threat to begin to decline by the end of the 1970s. By that time, the short

term threat had reached significant proportions. The backlog of programs began to flow into production, slowing the growth in the acquisition length and, in fact, causing it to be reduced in the late 1980s and early 1990s. When the short-term threat improves, the cycle which started at the beginning of the model run repeats itself. This mechanism for change in the acquisition cycle length results in similar changes in program cost, and was the dominant effect in the model output. This interaction among several negative feedback loops is shown in Figure 3.3.

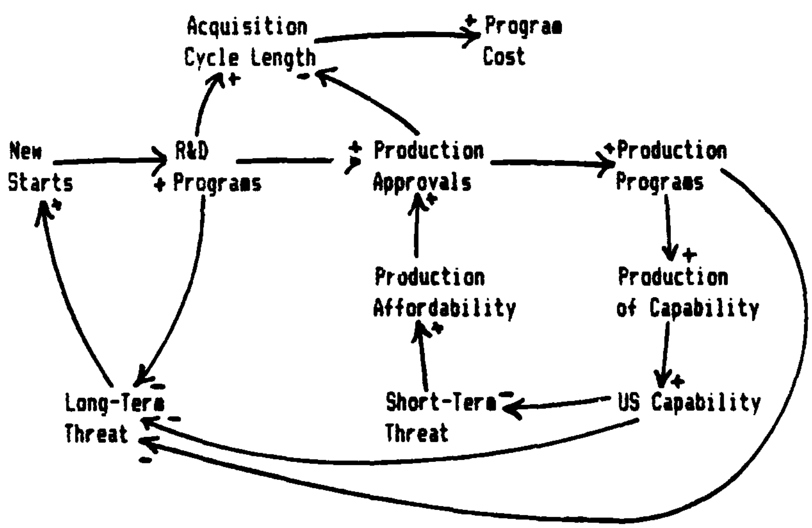


Figure 3.3
Causal Diagram of the Cyclical Behavior
of Acquisition Cycle Length and Program Cost

A 1977 Defense Science Board Study found that;

> The "bow wave" effect created by too many programs in full scale development at any given time in relation to the available production funds results in an acquisition cycle for the typical defense system which is in excess of the optimum length of time and is more costly than planned or estimated [6:1].

The same study concluded;

> <u>The time it takes therefore to get military equipment into the hands of the forces in the field is dependent almost entirely on when the money becomes available to buy it</u>. It is only loosely dependent, if at all, on when the development program started, on how much gold plating there is in the decision process, or on who happens to be sitting in the Pentagon. We can change our priorities and buy one thing before another, but the average procurement rate is fixed so long as we try to buy about the same number of systems [6:36].

It appears, therefore, that the same mechanism which produced cost and schedule growth in the model also produced them in the real DoD acquisition system in the 1970s.

The measure in the model for comparison of the US and enemy capability is the Raw Pressure for Acquisition, which is the ratio of enemy to US capability. Since capability in the model is measured as military investment accumulated over a twenty year lifetime, this measure is equivalent to the measure found in Secretary Weinberger's annual report to the Congress for fiscal year 1983 (36), as depicted in Figure 3.4. The graph shows that a steady increase of five percent per year in US military investment, while the Soviets do likewise, will result in a permanent deficiency in US cumulative investment. On the other hand, the figure shows that if the US military investment increases by fourteen percent per year, while the Soviets only increase investment by five percent per year, the present adverse trend will be reversed and the gap will be closed in the 1990s. As depicted in Figure 3.5, the behavior of the Raw

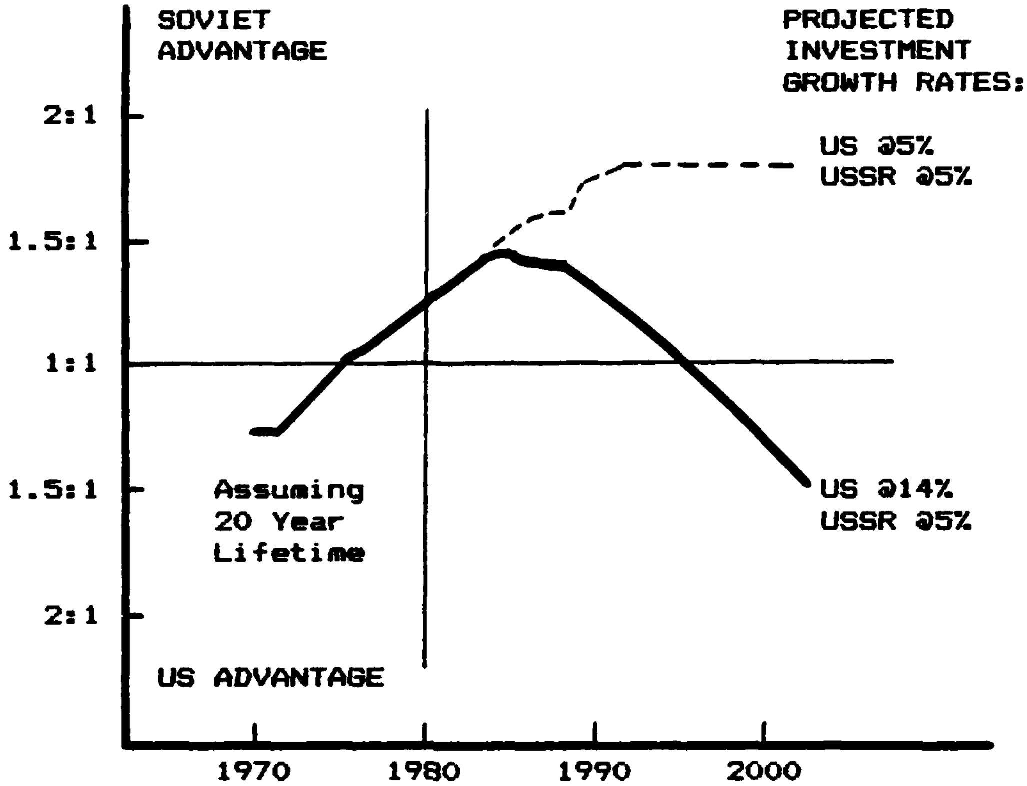


Figure 3.4
Ratio of Accumulated Military Investments

Pressure for Acquisition matches the actual behavior almost perfectly, and projects future behavior somewhere between the extremes shown in Figure 3.4. The reason for this behavior lies in the goal-seeking nature of the DoD acquisition system and several built-in negative biases in the structure of the system. The first, and perhaps most obvious, of the the negative biases is the fact that Congress almost never appropriates as much money for DoD as the President asks for. This bias, by itself, would almost certainly prevent the DoD from increasing its investment

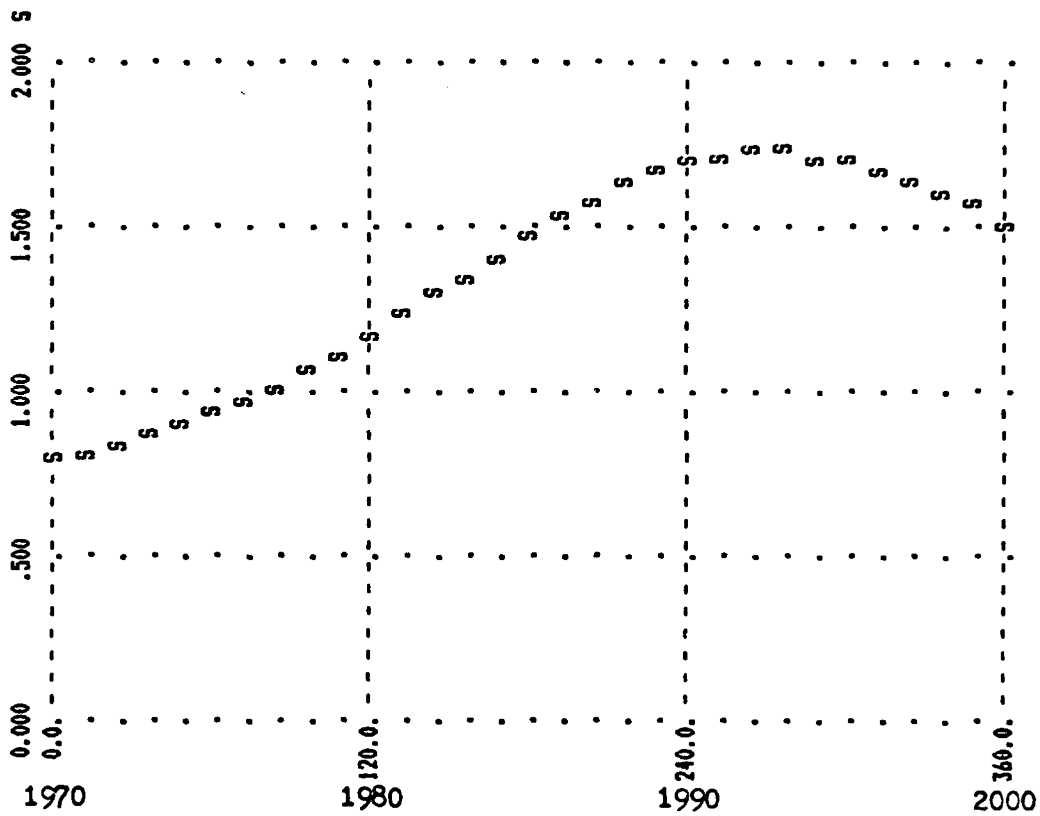


Figure 3.5
Model Output of Raw Pressure for Acquisition (S)

spending by fourteen percent per year for the next twenty years, since even if the GNP grew at an annual rate of five percent per year, the military investment as a fraction of the GNP would increase fivefold. A second source of bias is that the duration of programs is almost always longer than planned, and more programs are cancelled than forecast, resulting in a consistent overestimation of future US capability. This estimation error causes fewer programs to be started than would be required to actually achieve parity with the Soviets. A third source of bias arises from the

inescapable fact that the acquisition system is reactive in nature (36:I-11). The stated goal of the system is for US capability to be equal to enemy capability, but as enemy capability grows, the reactive nature of the system results in a tendency to lag behind the objective. This behavior is analogous to the behavior of thermostatically controlled heating system in which the temperature setting of the thermostat is continuously increased. The temperature of the room increases steadily, but will always lag the setting of the thermostat. The final reason for the behavior in Figure 3.5 is the arms race phenomenon. Whenever the US attempts to close the gap in military investment, a threat will be perceived by the Soviets, and they will increase their investment rate, making the gap even more difficult to close. Only one of the four sources of negative bias in the acquisition system is within the control of DoD acquisition policy: the length of the acquisition cycle and cancellation rate. To remove the other sources of bias would require a change in the structure of the system, such as a change in the US national goals and objectives.

The final problem symptom which motivated this research was the increasing technological obsolescence of the US weapons inventory (36:I-4,I-29). The variable used to measure this phenomenon in the model is the technological age. It is determined by computing the average level of technology applied to the existing weapon systems, and then

determining how long ago that level was the state-of-the-art. As shown in Figure 3.6, the model reflects the technological age of the DoD inventory increasing steadily since 1970, and the trend will continue until the late 1980s, when the fruits of the buildup that is now underway begin to be felt. The reasons for the growing obsolescence in the model and in the real system are the same:

> our collective failure to preserve an adequate balance of military strength during the past decade or two. While our adversaries engaged in the greatest buildup of military power seen in modern times, our own investment in forces and weapons continued to decline until recently [36:I-4].

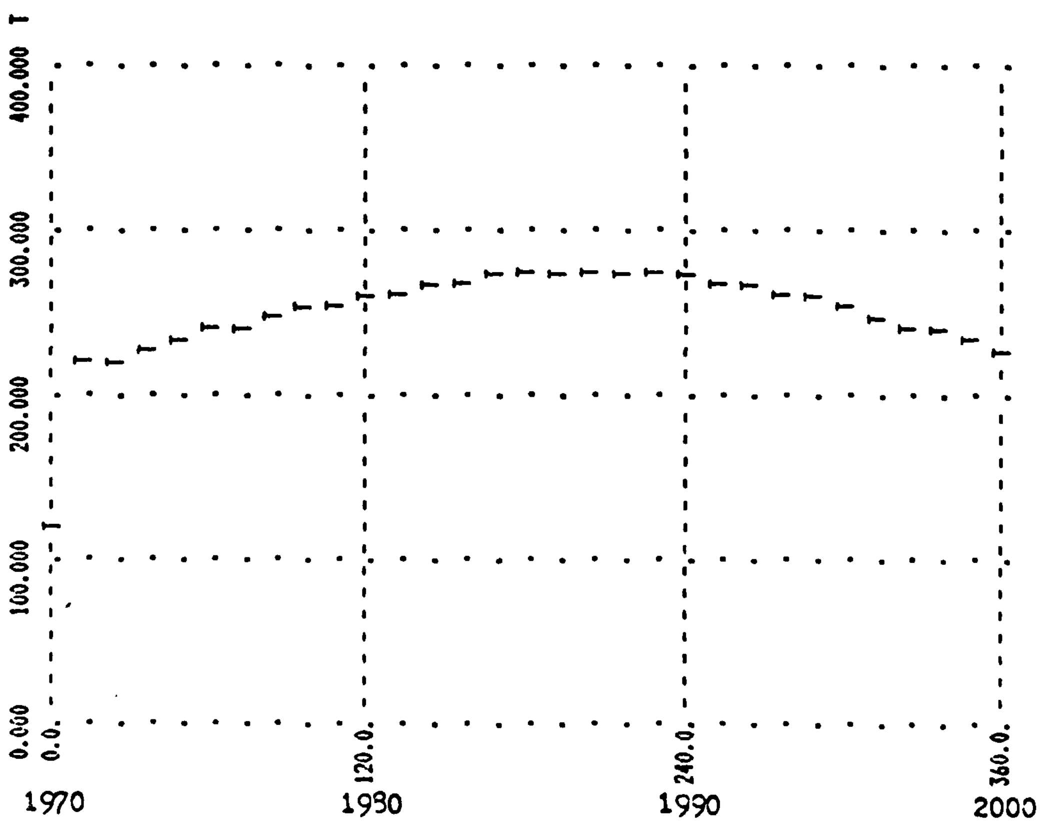
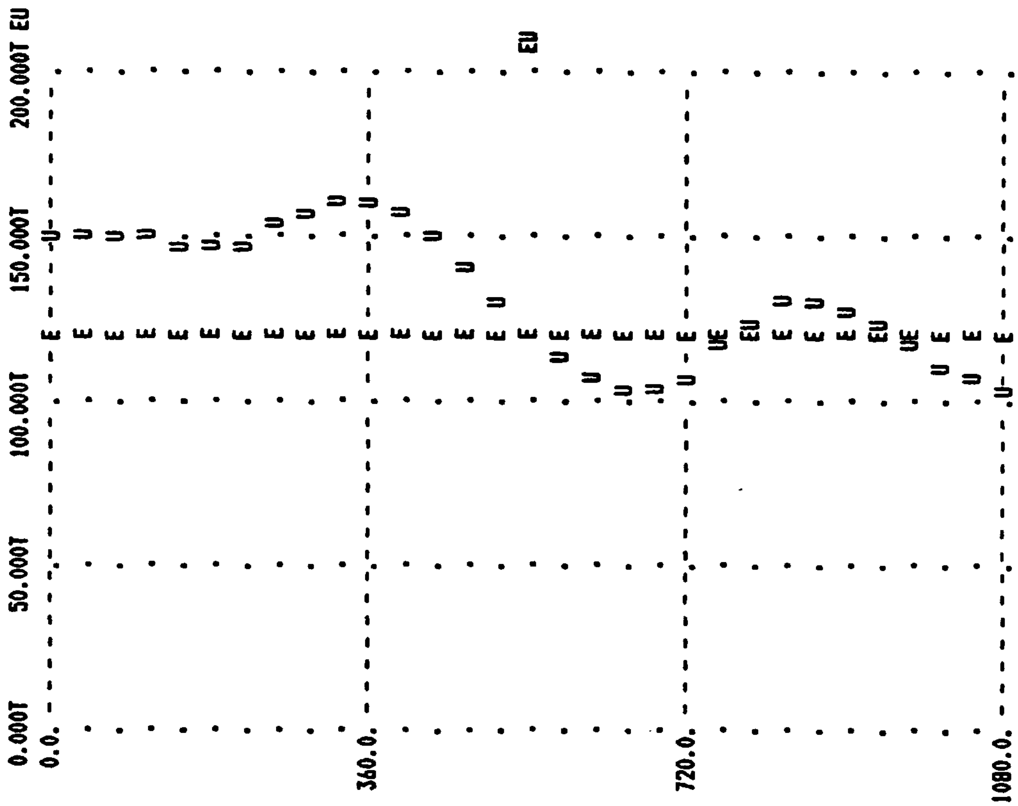


Figure 3.6 Model Output of Technological Age (T)

The reasons for "our collective failure" were discussed in the previous paragraph.

The multiple-mode test considers whether the model is capable of generating more than one mode of observed behavior. The behavior of the model can be modified significantly by varying the policies that guide its basic goal-seeking behavior. The existing model policies, as described in Chapter Two, lead to a situation in which the goal sought by the system is for US capability to be somewhat less than Soviet capability. By removing the negative bias that causes this behavior, the model can be made to generate oscillations of US capability about the enemy capability, as shown in Figure 3.7. Removing the negative bias requires making enemy capability constant, reducing cancellations, and providing sufficient funds to stabilize the duration of programs. Finally, by changing the goal of the system, the model can be made to drive the US capability into a mode of growth even beyond equality with the enemy, as depicted in Figure 3.8. The ability of the model to exhibit multiple modes of behavior lends confidence that the model is useful for policy analysis.

<u>Behavior-Anomaly Test</u>. During model development, numerous behavior anomalies were observed which led to reformulation of model equations in order to eliminate the anomalies.



E – Enemy Capability
U – US Capability

Figure 3.7 Capability Oscillations

Although the behavior-anomaly test is used extensively in model development, it can also play a broader role in validation. For example, one can often defend particular model assumptions by showing how implausible behavior arises if the assumption is altered [13:220].

An example of the use of this test in development of this model occurred during the testing of the Threat Sector, prior to its integration with the rest of the model. In order to test the sector separately, the remainder of the model was simulated with a simple delay of fixed duration to

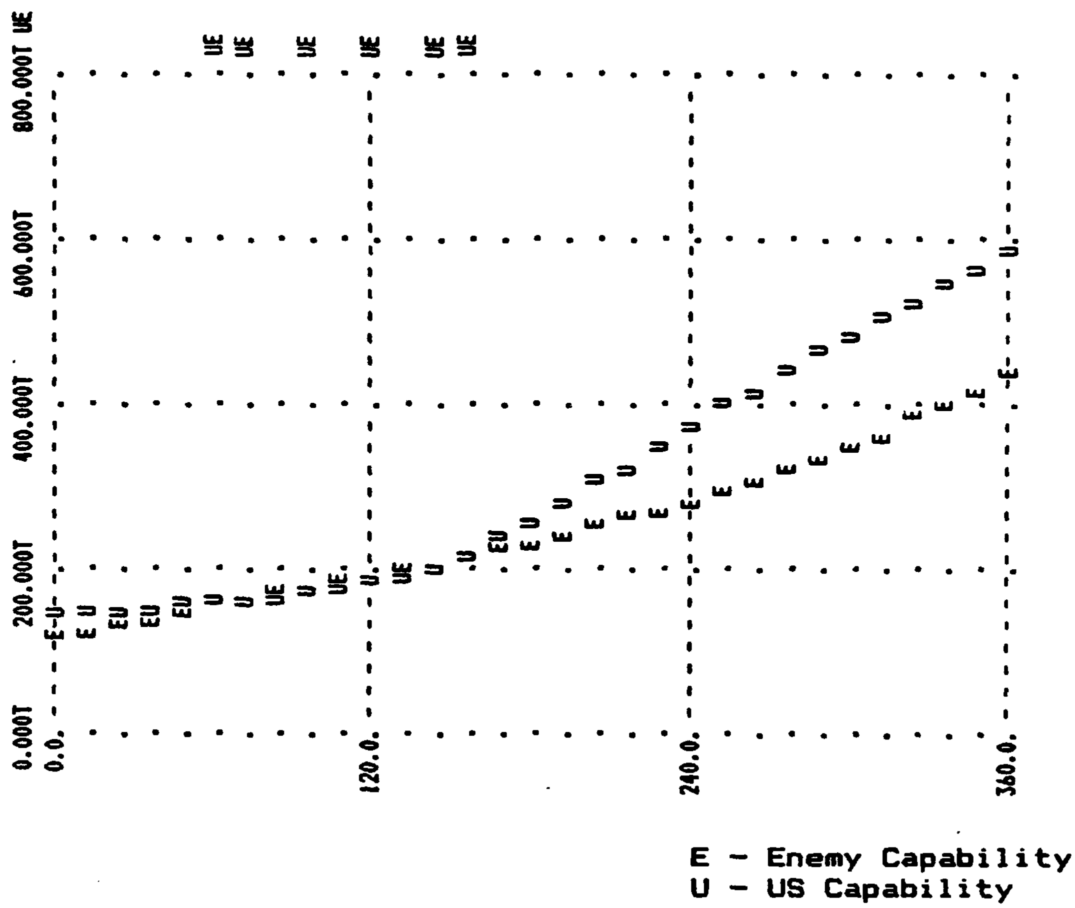


Figure 3.8 Changed Goal

represent the acquisition process. The original formulation had the new start rate growing by a factor equal to the long term threat at each time step. This formulation led to wild oscillations in US capability. It was determined that the input to the delay should be the long term threat multiplied by the output of the delay to prevent over-reaction to the threat. This modification led to reasonable behavior of the sector, and was kept when the model was integrated, in the basic form of the new start equation in the R&D Sector.

This formulation was found, as discussed in the surprise-behavior test below, to capture another important concept that was not realized at the time.

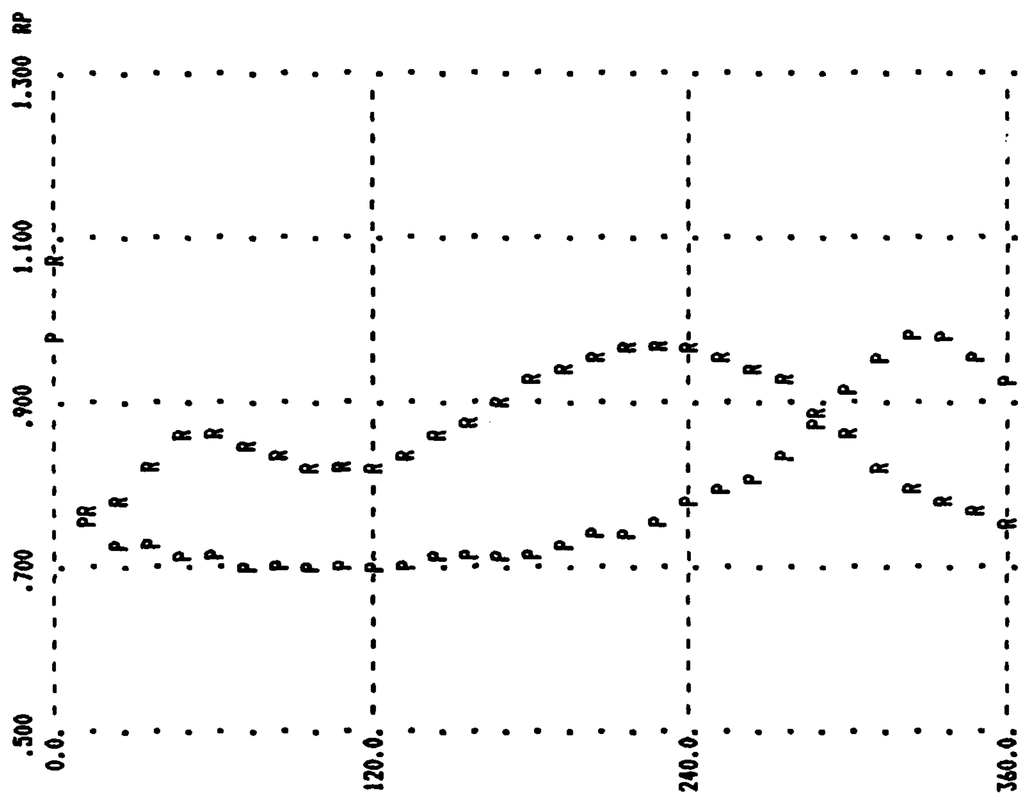
<u>Surprise-Behavior Test</u>. According to Forrester and Senge,

> The better and more comprehensive a system dynamics model, the more likely it is to exhibit behavior that is present in the real system but has gone unrecognized. Often such behavior emerges to the surprise of the model builder. . . When this procedure leads to identification of previously unrecognized behavior in the real system, the surprise-behavior test contributes to confidence in the model's usefulness [13:221].

The behavior anomaly which occurred during the testing of the Threat Sector resulted in the rate equation for new starts being formulated as a function of the production program termination rate, the long term threat, and a factor to account for expected cancellations. This structure was supported during the interviews based upon the fact that the total number of programs in progress cannot expand rapidly as a result of an increased threat, but grows gradually, due mostly to affordability considerations. This formulation was shown to generate steadily increasing new start rates during periods in which the US was behind in total capability. When the model was initialized with the US significantly ahead, however, the new start rate behaved reasonably at first, allowing a gradual reduction in the number of programs, but when the long term threat projection began to rise, the new start rate continued to decline for several

years. This behavior was due to a continuing decrease in the rate of production program completions, which was the result of earlier reductions in the number of programs. The model builders realized at this point that the formulation of the new start rate equation, as well as the affordability constraints in the R&D sector, effectively capture another concept which was not previously recognized. These equations represent, in addition to DoD affordability, a capacity constraint of the defense industrial base. Thus, after a period of neglect, the industrial capability was not immediately available to begin the needed buildup of systems. This behavior can be observed in the real system whenever a draw-down has occurred, followed by an attempt to build up.

Extreme-Policy Test. The extreme-policy test (13:221) consists of altering a policy (rate equation) in an extreme way and running the model to determine the reasonableness of the consequences. For example, the model was operated with the Funds Appropriation Ratio (FAR, the fraction of the budget request that is appropriated) set at constant values of .75, 1.0, and 2.0. The resulting model behavior was as one might expect the real system to behave. With the FAR of .75, the model attempted to adapt to severe shortage of funds by stretching and canceling programs. As shown in Figure 3.9, the combined effects of stretchouts and cancellations led to periods of time where the R&D and



R – R&D Funds Availablity Facto-
P – Production Funds Availability

Figure 3.9 Extreme Policy Test:
Funds Appropriation Ratio of .75

procurement funds availability factors were over 95 percent. However, the US capability, as displayed in Figure 3.10, declined for most of the model run, and began to increase only near the end of the thirty year run. The behavior of the model with a FAR of 1.0 was almost exactly the same as with the usual table functions determining the funds appropriation ratio. Finally, with the FAR of 2.0, the model managed to spend (waste might be a better term) most of the excess money by attempting to push programs much

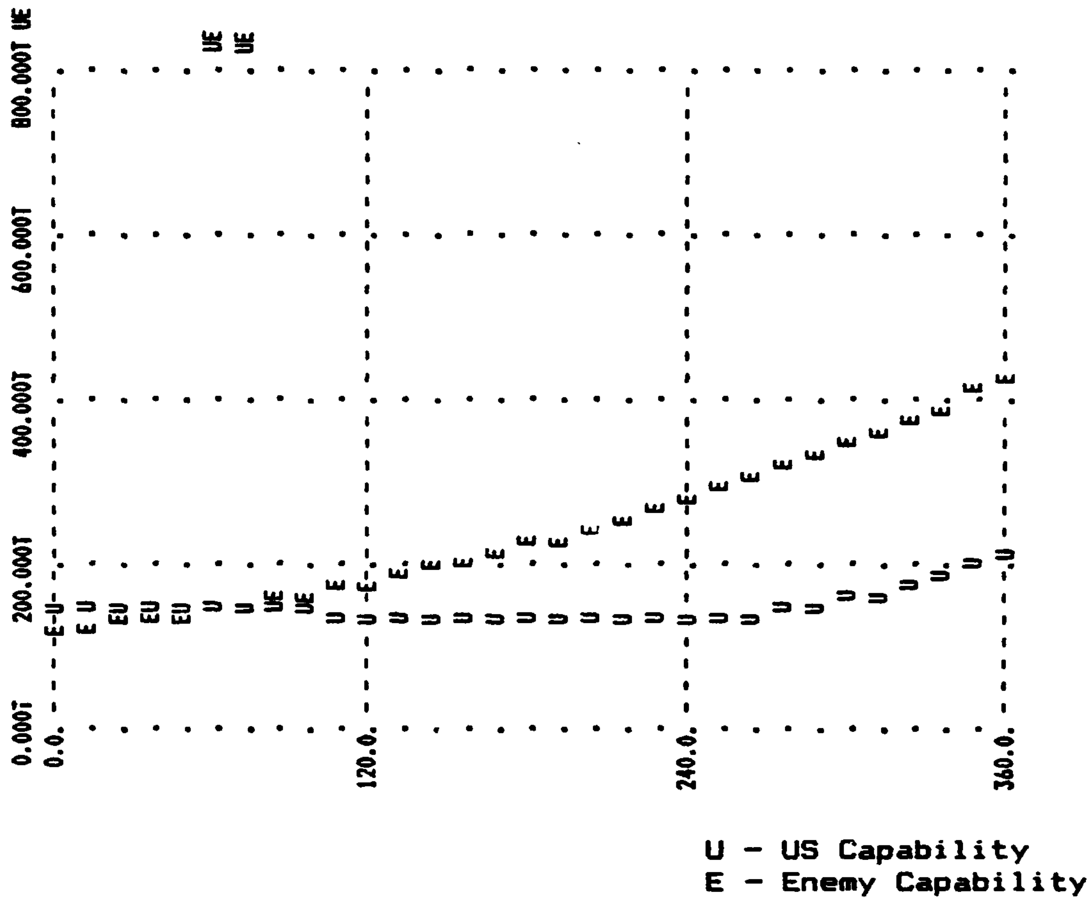


Figure 3.10
Capability Decline:
Funds Appropriation Ratio of .75

faster than is desired from a total cost standpoint, as shown in Figure 3.11. The extra funding was still not enough to completely overcome the affordability problem discussed previously. The duration of R&D began to lengthen after the model had used some of the extra money to start extra programs. The production duration was below the desired duration throughout the model run.

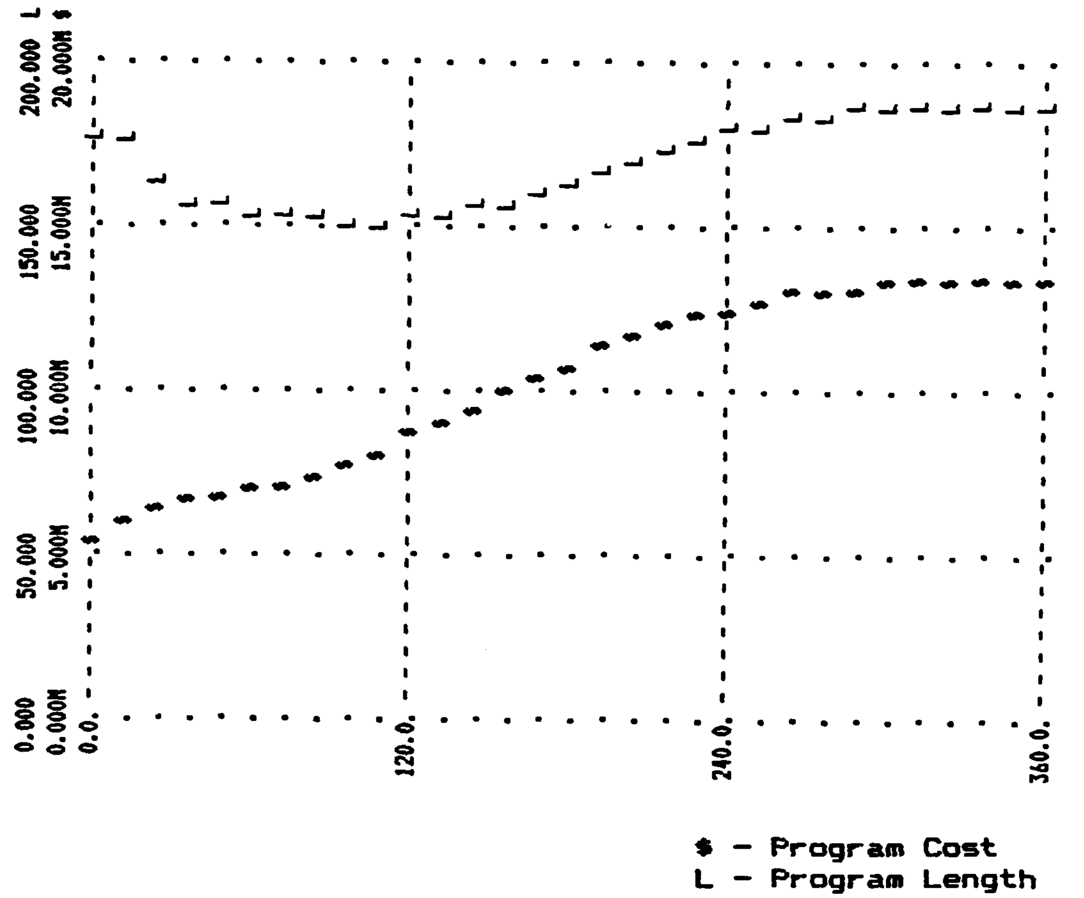


Figure 3.11
Extreme Policy Test:
Funds Appropriation Ratio of 2.0

In another extreme-policy test, the model was tested with the Technological Advancement Rating equal to a constant value of 16. This is equivalent to having the average of all weapon systems acquired being as technologically advanced as the SR-71 was at the time of its acquisition (24:Fig.2). The model behavior was again quite reasonable: the R&D duration became extremely long, resulting in the need for a very large number of programs with the size of the buy (number of production units per program) smaller

than it would have been with a lower technological advance rating. As a result, the US capability did not increase relative to the enemy capability nearly as rapidly as would be the case with a lower Technological Advance Rating.

A final example of an extreme policy test was the setting of the Management Reserve Factor at 1.25. This means that the DoD asks for 25 percent more each year than it needs. The policies for spending the management reserve remained unchanged, and the result was that the system could never spend all of the management reserve, even in the last quarter of the year when it would be allowed. The reason for this behavior is that the affordability constraints, which also represent industrial capacity as discussed above under the surprise-behavior test, prevent sudden surges of this magnitude in spending. The system never found itself with a shortage of funds, however, so program durations stayed at or below the optimum levels throughout the model run. Given the spending policies on management reserves, this behavior is quite realistic.

Behavior-Sensitivity Test. The behavior-sensitivity test focuses on the sensitivity of model behavior to changes in the values of the model parameters (13:222). The test was performed on constants and table functions in the model with the general result that the model behavior is insensitive to changes in the parameter values. While certain parameter changes can generate changes in the manner

in which the model's basic goal-seeking behavior progresses, the basic model behavior does not change.

Summary

This chapter has described the test which were performed on the model in order to build confidence that the model is a useful tool for analyzing the effects of DoD policies on the acquisition system. The specific tests described here are only examples of the numerous tests that were conducted. Further testing of the model can always be useful.

> Validity as meaning confidence in a model's usefulness is inherently a relative concept. One must always choose between competing models. Often a model with known deficiences may be chosen, if it inspires greater confidence than its alternatives. This is especially true when decisions must be made. Validity is also relative in the sense that it can only be properly assessed relative to a particular purpose. It is pointless to try to establish that a particular model is useful without specifying for what purpose it is to be used. Experience has repeatedly shown that debates over the relative merits of different models are often irresolvable if the purpose of the model application has not been clearly stated [13:211].

The final set of tests, tests of policy implications, outlined in Table 3.1, will be discussed in the next chapter, along with the policy experiment that was performed using the model.

CHAPTER 4

POLICY EXPERIMENTATION

Introduction

Chapter 3 presented the results of numerous tests of the structure and behavior of the model. The results of these tests lend confidence that the model is useful as a policy analysis tool. This chapter, therefore, extends the operation of the model into the realm of experimentation with policy alternatives.

> Model-based policy analyses involve the use of the model to help investigate why particular policies have the effects they do and to identify policies that can be implemented to improve the problematic behavior of the real system. The goal is an understanding of what policies work and why . . .
>
> Policy alternatives in the real system correspond to one or a mixture of two kinds of model manipulations: parameter changes (including minor variations in table functions) and structural changes (changes in the form or number of equations). Both involve changing how decisions are made. Sensitive policy parameters in a model suggest leverage points in the real system -- places where a change in existing influences in the system would improve matters. Model changes involving new feedback structure suggest ways of manipulating information in the real system to improve behavior [27:321].

The results of policy analysis with this model, as with any analytical tool, provide information which a policy maker can use together with intuition, judgment, and experience to make policy decisions. The application of the model for policy analysis described in this chapter is

intended to provide the reader with an example of how to use the model as a policy development tool. Discussed in this chapter are: (1) the conceptualization and formulation of a policy alternative that was designed to alleviate some of the symptoms of difficulty that motivated construction of the model, (2) the results of implementing the policy alternative in the model, and (3) the final set of tests outlined by Forrester and Senge (13:224-6): tests of policy implications.

Alternative Policy Conceptualization and Formulation

The behavior of the DoD acquisition system, as described under the symptom-generation test in Chapter 3, has exhibited several problem symptoms which DoD policy should attempt to alleviate. After considering the causes of the symptoms, a policy was conceived to alleviate at least one of the causes of the observed problem behavior. The specific modifications to the model equations were then formulated to correspond to this conceptual policy alternative. Presented in the next two sections are the conceptualization and formulation of the policy alternative.

<u>Alternative Policy Conceptualization</u>. Chapter 3 contained a discussion of the increasing cost of acquiring weapons systems being directly related to the length of the acquisition cycle, and the length of the acquisition cycle also playing a role in the failure of the system to achieve

the stated goal of parity in capability between the US and the Soviet Union. In attempting to improve the behavior of the system, therefore, gaining control over the length of the acquisition cycle would appear to offer promise. To find a policy that might gain this control required investigation into the causes of the changes in the acquisition cycle length.

The growth in the acquisition cycle length, as described in Chapter 3, had two causes: a weak positive feedback loop relating short-term funding availability to stretchouts, and a more dominant negative feedback structure related to long-term affordability. While a negative feedback structure is goal-seeking and should be self-regulating, this particular structure oscillates over a fairly broad range and has a period of oscillation of three decades or more. Therefore, a policy which is aimed at controlling the range of oscillation of this negative feedback structure would be appropriate.

During the upswing of the acquisition cycle length, the major mechanism for causing schedule growth is that more programs are in progress in the R&D process than the DoD can afford to complete, and the non-affordable programs are allowed to remain in the present phase until an opportunity arises for them to continue to the next phase, causing a backlog of non-affordable programs. The policy alternative that immediately comes to mind to alleviate this problem is

to cancel those programs that are not affordable. The DoD Acquisition Improvement Program addresses this policy alternative in the initiative on integrating the Defense Systems Acquisition Review Council (DSARC) and the Planning Programing and Budgeting System (PPBS) processes. The alternative selected by DoD for implementation provides that

> . . .programs reviewed by the DSARC will be accompanied by assurances that sufficient agreed to resources are in the FYDP and EPA or can be reprogramed to execute the program as recommended. DSARC review would certify the program ready to proceed to the next acquisition stage. Affordability in the aggregate would be a function of the PPBS process [3:34].

During the interviews, it was found that the combination of this initiative and the initiative on increasing program stability (3:4) is leading to a policy of cancellation of programs that are not affordable.

<u>Alternative Policy Formulation</u>. Formulation of an absolute policy of canceling non-affordable programs is straightforward. If the number of programs completing a phase is greater than the number of that can affordably enter the next phase, the programs representing the difference between the completions and the affordable programs are canceled. The cancellation rate equations in the model would therefore be modified using a clip function, as follows:

```
R VCNX.KL=VP.K*VCF.K+CLIP(0,PVCR.K-DAFD.K,
        DAFD.K,PVCR.K)
R DCNX.KL=DP.K*DCF.K+CLIP(0,PDCR.K-PAFD.K,
        PAFD.K,PDCR.K)
```

DAFD = Development Affordability
(programs per month)
DCF = Development Cancellation Factor
(fraction per month)
DCNX = Development Cancellation Rate
(programs per month)
DP = Development Programs (programs)
PAFD = Production Affordability
(programs per month)
PDCR = Potential Development Completion Rate
(programs per month)
PVCR = Potential Validation Completion Rate
(programs per month)
VCF = Validation Cancellation Factor
(fraction per month)
VCNX = Validation Cancellation Rate
(programs per month)
VP = Validation Programs (programs)

The policy represented by the above equations is absolute and may not be possible to implement realistically. A more realistic implementation might be to phase in, over a period of time, a policy of canceling some fraction of the non-affordable programs. The equations for testing the policy alternative are therefore:

```
R VCNX.KL=VP.K*VCF.K+SMOOTH(PEFF.K,PITIME)
        *CLIP(0,PVCR.K-DAFD.K,DAFD.K,PVCR.K)
R DCNX.KL=DP.K*DCF.K+SMOOTH(PEFF.K,PITIME)
        *CLIP(0,PDCR.K-PAFD.K,PAFD.K,PDCR.K)
A PEFF.K=CLIP(PEFFC,0,TIME.K,144)
C  PEFFC=.8
C  PITIME=24
```

PEFF = Policy Effectiveness (dimensionless)
PEFFC = Policy Effectiveness Constant (dimensionless)
PITIME = Policy Implementation Time (months)

The policy effectiveness is the fraction of the non-affordable programs that will be canceled when the policy is fully implemented, and the implementation time is the time

required to phase in the new policy. In the model, the implementation is to begin at Time 144 months, which would correspond to 1982 in the model which is initialized at approximately 1970.

The above equations were inserted into the model and the model was operated to observe the effects of the changed policy. The next section presents the results of the policy experiment.

Results of Policy Experiment

The results of the policy experiment were generally as expected. The cancellation of programs that were not affordable reduced the backlog of full scale development and validation programs, thereby reducing the acquisition cycle length and program cost. Figure 4.1 depicts the model response to a policy effectiveness of .8 and implementation time of 24 months. The dashed lines show the original model behavior, as presented in Chapter 3, for comparison. The delays in the response of the acquisition cycle length and program cost are the result of the fact that they are both measured for programs which are being completed at the present time. Thus, for several years after the new policy is implemented, the programs being measured are programs which spent much of their lifetimes operating under the old policy.

The policy test was repeated using the DYNAMO (25) rerun option to determine how sensitive the results are to

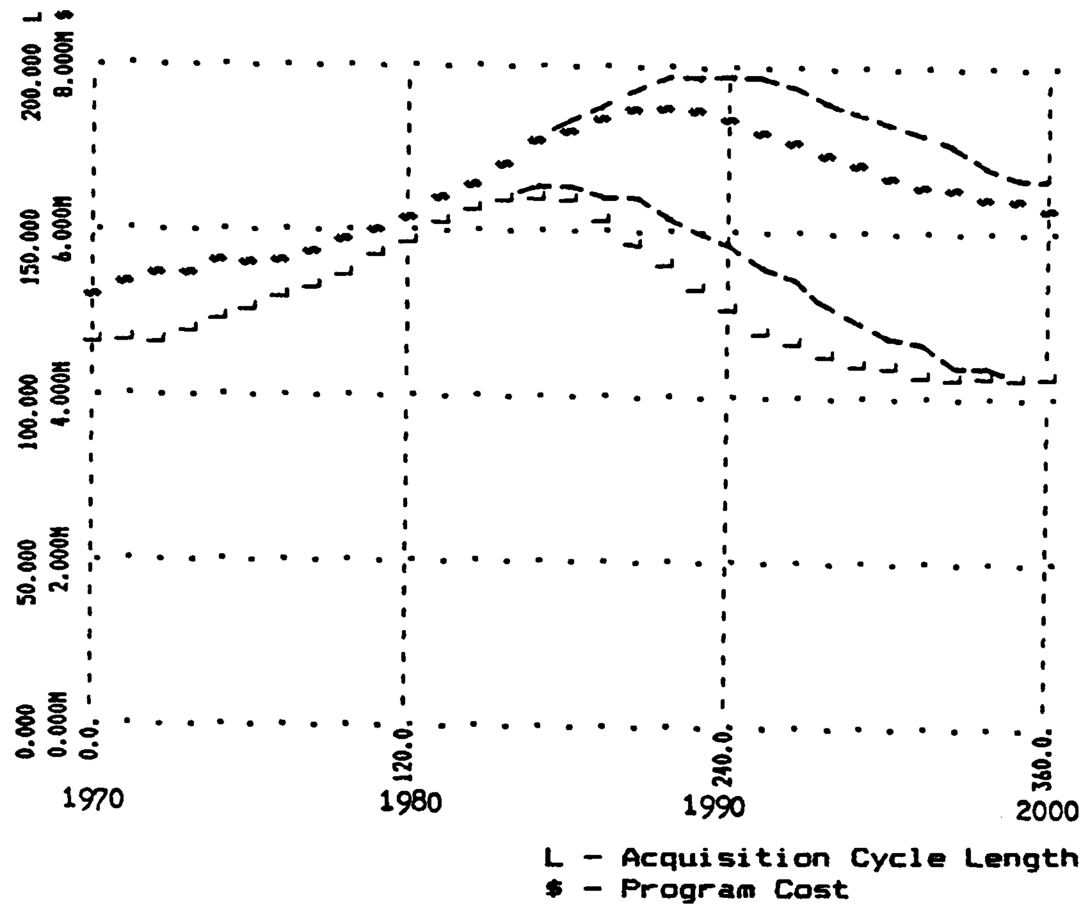


Figure 4.1 Policy Experiment Results

varying the time required to implement the policy and the proportion of non-affordable programs to be canceled. It was found, as expected, that the more quickly the new policy is implemented, the more dramatic are the resulting reductions in acquisition cycle length and program cost. Also, the larger the proportion of non-affordable programs that are canceled, the more dramatic the result. However, even a relatively modest policy of canceling half of the non-affordable programs, phased in over four years, still had noticeable results.

Tests of Policy Implications

The last set of tests outlined in Forrester and Senge (13:224-226) are the tests of policy implications (see Table 3.1).

> Policy-implication tests attempt to verify that response of a real system to a policy change would correspond to the response predicted by a model. The tests also examine how robust are policy implications when changes are made in boundaries or parameters [13:224].

Since the major purpose of the policy experiment in this research was to provide an example of how the model could be used for policy analysis, the testing in this area was not extensive. This discussion will therefore be limited to a description of the tests, and how they might be applied to the experiment in this chapter.

System-Improvement Test. The system-improvement test is the ultimate test of a system dynamics model. The test considers whether the policy which was found to improve the behavior of the model also improves the behavior of the real system.

> Although it is the ultimate real-life test, the system-improvement test presents many difficulties. First, it will not be tried until the model from which the new policies come enjoys enough confidence for the implementation experiment to be made. Second, if the real-life experiment is made and the results are as predicted, the test is often clouded by the assertion that the beneficial results came from causes other than the new policies. No matter what the outcome, interpretation of the actual policy implementation is invariably subject to uncertainty as to whether or not other conditions were adequately constant to permit attributing the results to the policies. Third, the very long time required for reaction in most social systems

(running to months or years for a corporation, and to decades for the national economy) mean that results of the system-improvement test accumulate slowly [13:224].

To accomplish the system-improvement test with regard to the policy experiment conducted in this research would require the DoD to implement a policy of canceling non-affordable programs and to observe the results for at least a decade or two.

Changed-Behavior-Prediction Test. The changed-behavior-prediction test asks whether the model can correctly predict how the behavior of the system will change if a policy is changed. The test can be made in several ways:

> Initially, the test can be made by changing policies in a model and verifying the plausibility of the resulting behavioral changes. Alternatively, one can examine the response of a model to policies which have been pursued in the real system to see if the model responds to a policy change as the real system responded. If the model represents a family of systems, some of those systems will probably be operating under different policies, and the policies of the model can be altered to see if its behavior takes or the different behaviors that distinguish members of the family [13:224-225].

The policy experiment implemented in this chapter provides an example of the weakest form of this test. The results of the experiment were plausible, after having reasoned through the cause and effect relationships of the problem at hand, and the expected effect of the policy change.

Boundary-Adequacy (Policy) Test. As a policy test, the boundary-adequacy test examines whether changing the model boundary alters the policy implications of the model.

The test involves conceptualizing additional structure and analyzing the effects of the additional structure on the model behavior and policy implications. An example of this type of test would be the addition of feedback structure to alter the Technology Advancement Rating as a response to threat, and program cost, as is suggested in the Recommendations for Further Research in Chapter 5.

Policy-Sensitivity Test. Parameter sensitivity testing can be used to indicate the degree to which policy recommendations might be influenced by uncertainty in parameter values.

> Such testing can help to show the risk involved in adopting a model for policy making. If the same policies are recommended, regardless of the parameter values within a plausible range, risk in using the model will be less than if two plausible sets of parameters lead to opposite policy recommendations [13:225-226].

A matter of uncertainty to which the policy experiment conducted in this research might be particularly sensitive is the question of exactly where the DoD acquisition system is today, relative to the cyclical behavior in the acquisition length. An experiment was conducted to determine the sensitivity to this question, and it was found that if the system is still early in the upswing of the cycle, the policy recommendations remain unchanged, and the effect of the policy change is more dramatic. However, if the system has already reached the peak of the cycle, the policy of canceling non-affordable programs will have no effect

until the next upswing in the cycle begins, perhaps twenty years hence.

Chapter Summary

This chapter has provided an example of how the model developed in this research can be used for policy analysis. The topics discussed were: (1) conceptualization and formulation of an alternative policy, (2) the results of the experiment, and (3) the tests which can be performed to build confidence in the policy implications of the model.

Chapter 5 summarizes the research effort, makes recommendations for future research, and presents the conclusions of this research effort.

CHAPTER 5

SUMMARY, RECOMMENDATIONS, AND CONCLUSION

The primary objective of this research was to provide a validated policy model of the DoD acquisition system. A dynamic policy model was developed, and initial validation of the model accomplished. The model was developed at a high level of aggregation and, as is true of any dynamic policy model, will never be totally complete or have absolute validity. The model developed represents the acquisition process and its environment and should be used for policy analysis and investigation of the dynamic relationships in the DoD weapons acquisition system. Use of the model should include expansion of the policies and feedback relationships that cause pressure for policy changes in the system. Several examples of additional relationships that can be developed are presented in the recommendations for further research in this chapter. Before presenting those recommendations, a brief summary of the model is presented.

Model Summary

The system dynamics methodology was used to develop a dynamic policy model of the DoD acquisition system. This section summarizes the conceptual structure of the model, the division of the system into five sectors, the inter-

actions among the sectors, and the structure of the individual sectors.

Conceptual Structure. The acquisition system, as modeled in this research, consists of the acquisition process itself and the environment in which the process operates. The acquisition process includes research and development as well as production of weapon systems. The environment includes the threat posed to the US by its potential adversaries, the availability of technology, and the political and economic influences which make themselves felt primarily through the availability of funds for the acquisition of weapon systems.

The first step in developing the system structure was to define the purpose or goal of the acquisition system. The goal of the acquisition system is to provide the weapon systems necessary to defend the US and its interests and to deter aggression. This goal was operationalized in the model by further defining the goal as maintaining parity in the aggregate measure of capability between the US and its principal adversary, the Soviet Union. The measure of aggregate capability that was chosen for comparison in the model is the US and Soviet military investment spending (RDT&E and procurement), accumulated over the life of the hardware. This comparison of capability provides a measure of the need for acquiring weapon systems and the urgency of that need.

The acquisition process responds to the need for additional capability by starting programs which progress through research and development, and eventually enter production, where they provide capability to the DoD. The rate of progress of programs through this process is constrained by the availability of technology that is to be used in the new weapon systems, and the resources that are required to accomplish the necessary work and to purchase the final hardware. The availability of funding is determined primarily by political and economic pressures that are felt by the Congress.

Model Sectorization. Once the key relationships of the DoD acquisition system were identified, the system was divided into five functional sectors which were developed and tested independently and then integrated to form the model of the system. Sectorization allowed the researchers to decompose the complex system into manageable parts for the purpose of model formulation. The five sectors are: research and development, production, financial, technology, and threat. These five sectors correspond to the major functional areas of the acquisition process and the environment. The five sectors and their interactions are shown in Figure 5.1. The R&D and production sectors represent the acquisition process in which programs flow from R&D into production, where military capability is produced. The other three sectors represent the environment of the

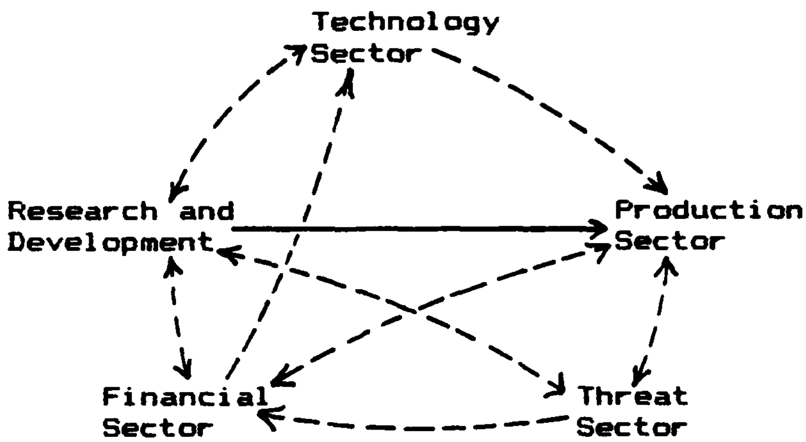


Figure 5.1
Sector Interaction Diagram

acquisition process. These environmental elements influence the acquisition process by providing external pressures and constraints within which the process must operate. The environment also is acted upon by the acquisition process in several ways. The availability of funding determined in the financial sector is at least partly determined by the need for acquisition funds and the efficiency with which the acquisition process operates. The pressures for acquiring weapon systems which come from the threat sector are affected by the acquisition process in two ways. First, an increase in the US capability or forecasted capability will, all other things remaining constant, reduce the need for new weapon systems. Second, an increase in the US capability will result in an increased threat being perceived by the Soviet Union, which will then increase its capability. This

increase in Soviet capability will create additional pressure for the US to acquire weapons, and represents the arms race. Finally, the availability of technology is influenced by the amount of technological advancement being sought in the R&D process, as well as by the availability of funding in the financial sector. The internal structure of each of the sectors is summarized next.

Research and Development Sector. Within the R&D sector, acquisition programs are created and the progress through three of the four phases of the acquisition process: concept exploration, demonstration and validation, and full scale development. The concept of a program in the model considers programs in the aggregate sense as a means of procuring military capability. In the model, individual programs are not identifiable, but rather represent an average of the acquisition programs in process. The R&D sector contains the policies and decision structures necessary to control the flow of programs from start through either production approval or cancellation. The R&D sector also generates information used in the financial sector to determine budget requests and spending rates and in the threat sector for forecasting future US capability. After being approved for production, programs enter the production sector.

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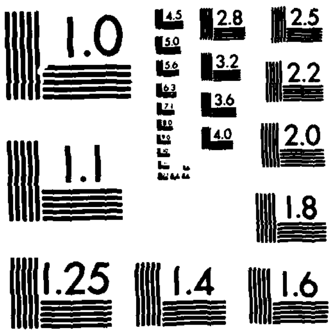

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Production Sector. The production sector contains the model structure for both production of new weapon systems and modification of existing systems. The production sector includes policy structure for controlling the flow of production programs and for determining rates of production of new weapon systems and modification of existing systems. The production sector also contains the model structure for measuring the accumulation of US military capability which is used in the threat sector for comparison with enemy capability. The production sector provides information to the financial sector for use in determining budget requests and spending rates. The remaining sectors of the model provide the environment in which the acquisition process operates.

Financial Sector. The financial sector provides the constraining influence of funding availability to the acquisition process. In the financial sector, budget requests are determined from the information obtained from the R&D, production, and threat sectors. The budget requests are then modified using economic and political factors to determine the amounts appropriated by the Congress. The economic and political factors include the Congressionally perceived threat, the size of the DoD budget request as a fraction of the GNP, the demand for non-defense spending, and the fiscal policy needs of the economy. The financial sector provides information on funding

availability to the R&D and production sectors for use in controlling the rates of R&D progress, production, and modification. These rates are then used in the financial sector to determine the spending rates and then to update the amount of funds available. The ratio of appropriations to the budget requests is also used in the technology sector in determining the rate of technology growth.

Technology Sector. The technology sector provides information to the R&D and production sectors regarding the state of technology and its growth rate. For modeling purposes, technology was defined as the amount of capability that can be obtained from one unit of production (for example, one airplane or tank). Two levels of technology are defined in the model: available and applied technology. Available technology is the level of technology that has been discovered and tested to the point that applying it to production may begin. Applied technology is technology that has been transferred from available to application in the production process. The technology sector contains relationships for determining the complexity of weapons being developed, the time required in the validation phase for achieving the desired amount of technology growth, and the amount of technology being applied to production, which determines the capability of the weapon systems being produced. The technology available is also used in the

production sector as a factor in determining the amount of modification that can be accomplished.

Threat Sector. The threat sector determines the threat which drives the other sectors of the model by providing measures of the need for acquisition of weapon systems and the urgency of that need. The threat sector accomplishes this by comparing existing and forecast enemy and US Capability. The threat sector also contains the mechanism for determining the enemy military investment spending from the threat perceived by the enemy. This spending is converted to enemy capability by using US R&D and production costs. The comparison of forecast US and enemy capability is used in the R&D sector as a factor in determining the rate of new program starts and the affordability of the R&D phases. The long-term threat is also used in the financial sector for determining the R&D budget request in view of the affordability issue. The comparison of existing US and enemy capability is used as a factor in determining production affordability, the rate of modifications, and the ratio of appropriations to budget requests.

The model of the DoD acquisition system was subjected to numerous tests of its structure and behavior for the purpose of building confidence in model usefulness as a policy analysis tool. Use of the model to test a specific policy was demonstrated, as reported in Chapter 4.

Recommendations for Future Research

The model developed in this research provides a broad-based structure of the DoD acquisition system which is a useful tool for policy analysis and for understanding the complex interactions in the acquisition system. No dynamic policy model is ever totally complete, however, so there are several areas in which further research would be useful, in order to increase the realm of policy areas for which the model is a useful analysis tool.

Technological Advancement. In the model, the technological advancement rating, the amount of push for new or advanced technology in acquisition, was modeled as a constant to be selected for any particular model run, as though it were a simple policy variable. In the aggregate, this variable is not believed to change very rapidly, so the modeling of the variable as a constant probably does not affect the overall outcome of model runs of 20 to 30 years. However, there is a feedback structure in the acquisition system that influences the value of the technological advancement rating. An increase in the projected threat may, in fact, result in an increase in the technology being sought, while a lengthening of the acquisition cycle may create a pressure to reduce the technological sophistication of weapon systems being acquired. The precise structure of these relationships could be investigated and included in the model. The inclusion of this additional structure would

add to the usefulness of the model by making it possible to use the model to evaluate policy alternatives regarding how the policies on technological advancement are derived.

Risk Analysis. In several places in the model, cost and schedule changes are assumed to occur as deterministic results of environmental forces on programs, such as a shortage of funds, or an increase in the amount of technological advancement being sought. In fact, some of these causes of cost and schedule growth in the model result in increased cost and schedule risk in the real system, and do not necessarily result in actual cost or schedule growth. This could be included in the model by making the costs and durations of phases stochastic instead of deterministic. The variables that now directly affect cost and schedule would instead impact the parameters of the probability distribution functions for the costs and durations. Decision structures in the model could then be based upon the degree of risk involved in various alternatives. Inclusion of this structure in the model would allow the model to be used for evaluation of policy areas concerning the management of risk in acquisition programs.

Defense Contractors. In its present form, the model does not explicitly include defense contractors and their responses to DoD policies and the economic climate. Inclusion of additional structure in the model to capture

the reaction of the defense contractors to the policies and decisions of the DoD would expand the model's completeness, and allow analysis of policies involving contract type selection and risk sharing between Government and industry, for example. The contractor would interface with the current model in both the R&D and production sectors. In R&D, the performance of industry would provide the cost and time required for development of weapon systems, as a result of the demands and resources made available to the contractor from DoD. The contractor interface in production would include the interaction between the Government and the contractor including the structure necessary to model variable lead times and contract types, and the effects of the economy and DoD policy on cost and availability of production. Inclusion of the contractor would also allow the model to be used for evaluation of policies dealing with surge capability, and the tradeoff between surge capability and the cost of maintaining inventories of long-lead production items.

Conclusion

In conclusion, the objective of this research was accomplished. A broad based policy model of the DoD acquisition system has been developed and initial validation accomplished. As a policy analysis tool, the model can provide additional information for a policy maker to use in conjunction with intuition, judgment, and experience to

evaluate proposed policy changes and the effectiveness of existing policy. The model is also useful as an aid to understanding the complex interactions in the DoD acquisition system. Finally, recommendations have been made for further research which will enhance the model's usefulness for both policy analysis and understanding of the DoD weapons acquisition system.

APPENDIX A

INTRODUCTION TO CAUSAL DIAGRAMS, FLOW DIAGRAMS, AND DYNAMO TERMINOLOGY

Introduction

Causal diagrams and flow diagrams are tools used in system dynamics as an aid to visualizing the structure and relationships of a system during the conceptual and formulation phases of model development. This appendix contains a very brief introduction to causal and flow diagrams, and the symbology used in this report.

Causal Diagrams

Causal diagrams are used in systems analysis to visually depict the structure and fundamental relationships between elements of the system. Connections between variables are depicted by arrows, or causal relationships, that are either positive or negative in nature. The positive relationships shown in Figure A.1 indicate that an

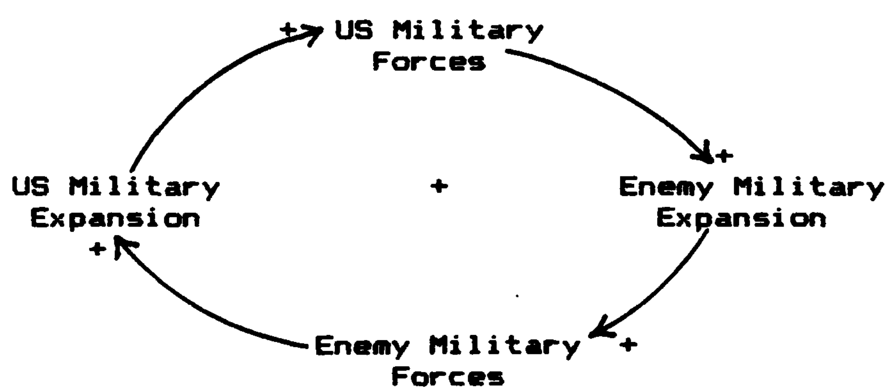

Figure A.1 Positive Feedback Loop

increase in any one variable will result in an increase in the next variable in the loop. A minus sign indicates that

an increase in the tail variable results in a decrease in the variable at the head of the arrow. When the net sign, found by multiplying all the signs together of a closed loop is positive, the loop is a positive or reinforcing loop. Once a balance in the positive loop is changed, maybe the enemy increases their force level, the forces in the loop will drive continuously in an increasing growth of forces on both sides unless there is a restraining influence not shown in Figure A.1.

Figure A.2 depicts a negative or goal seeking loop that tries to maintain a balance or equilibrium when disturbed by an outside element.

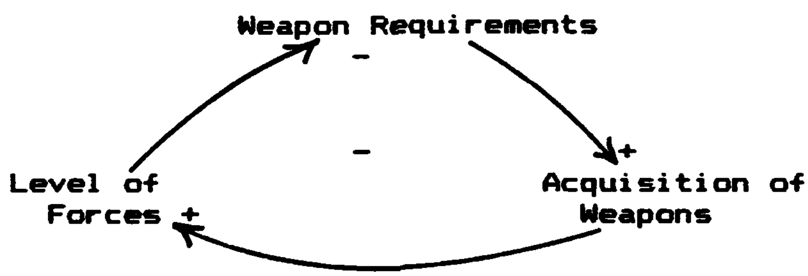

Figure A.2 Goal Seeking Loop

The primary function of developing an influence diagram is the determination of what variables interact in the system under study, and indentification of feedback relationships within the system. During the development of the system influence diagram(s), the system boundaries and nature of required exogenous variables are defined. The

reader is referred to Forrester (10) and Richardson and Pugh (27) for a more complete explanation of causal diagramming.

Flow Diagrams

Flow diagrams provide an intermediate step between the very general variable relationships found in the influence diagram and the explicit mathematical relationships in a computer model. Each variable that will be used in the model is identified in a flow diagram and the connection of arrows pointing to a variable indicate all the elements used in the calculation of the variable. The symbology used in this report for flow diagramming is shown below. For a more detailed explanation of flow diagramming and DYNAMO symbology refer to Richardson and Pugh (27).

Symbol	Equation Type
Concept Programs (CP) RD10	- level

NOTE: CP is the program variable and RD10 is equation number where the variable is defined.
RD = Research and Development Sector
P = Production Sector
F = Financial Sector
TE = Technology Sector
TH = Threat Sector

Symbol	Equation Type
New Starts (NS) RD1 ⋈	- rate
Validation Affordability (VAFD) RD9	- auxiliary

Symbol	Equation Type
Concept Cancellation Factor (CCF) RD4	- table function
Concept Duration (CDUR) RD8	- constant
DELAYP: US Obsolescence Rate (UOR) P31; US Capability (UCAP); OLTIME	- pipeline delay
SMOOTH: Capability Growth Factor (CAPGF) F12	- smooth of CAPGF defined as an auxiliary equation
	- source or sink for flows into or out of the system boundaries
--- D --->	- delayed information flow
--- S --->	- smoothed information flow

NOTE: UOR is the rate of flow out of the delay, UCAP is sum of the capability held in the delay, and OLTIME is the length of the delay.

DYNAMO Equations

Six types of DYNAMO equations were used in this model. The equation category is defined by the letter in column one of the model listing. Each of the six types is listed below with a brief definition. Detailed discussion of the equation types and use is presented in Pugh (25) and Richardson and Pugh (27).

Type	Definition
L	– Level equation. Accumulation of quantities flowing in and out of the level.
R	– Rate equation. Rate of flow of a quantity.
A	– Auxiliary equation. Used as an intermediate calculation for a rate.
C	– Constant. Variable defined to have a constant value for the entire run of the model.
N	– Initial value for variable.
T	– Table of dependent values used by TABLE function.

APPENDIX B

INTERVIEW GUIDES

INTERVIEW GUIDE (Initial Interviews)

1. Introduction and Overview (5 min)

Introduce self.

Introduce purpose and topics for interview.

A. The purpose is to gather first hand information to:

1). verify (or discredit) our initial conceptual concepts, to

2). more precisely define the reference modes of the system, and

3). gather information for use in modeling the specific relationships for the DSARC/PPBS interface.

B. Topics to be covered are:

1). the role of your organization in the acquisition process,

2). the DSARC/PPBS interface,

3). the concepts of cost, schedule, and capability,

4). a recent acquisition decision, and

5). acquisition funding.

Overview our project. (Introduce the influence diagram) POLICY Model of the DoD Acquisition System.

2. Discuss the role of your organization within the acquisition system. (10 min)

3. DSARC-PPBS Interaction (15 min)

A. Describe a key connection between the DSARC and PPBS.

B. At the time of approval for the Justification for Major System New Starts, how much of the program is in the FYDP? (just concepualization, or beyond?)

C. Is a tentative or informal approval of a program required before its funding will be included in the POM and FYDP? (outyear funding for F/S Dev or production at milestone II?)

D. What one change would you like to make in the DSARC/PPBS interface?

1). How would this change impact the system?

2). Describe a specific example?

4. Cost, Schedule (program progress?), and Capability (15 min)

A. How do you measure cost, schedule, and capability?

1). Cost possibilities: total system costs, lifcycle costs, or production cost/unit, etc.

2). Schedule possibilities: DSARC timeliness, production completion, operationally effect date, etc.

3). Capability possibilities: unit performance, integrated with supportability, total system effectiveness, etc.

B. What do you feel is the primary contributor to program cost growth?

C. What do you feel is the primary contributor to schedule slippage?

D. Given a choice of the following tradeoffs, which would be preferred?

1). Cost vs Schedule?

2). Cost vs Capability?

a). reducing the "buy"

b). reducing performance requirements

3). Schedule vs Capability?

C. Is there a "threshold" beyond which programs are considered for cancellation or are cancelled?

5. Recent Acquisition Decision (Policy or Program) (10 min)

A. Describe a decision you made recently.

1). What was the origin of the decision requirement?

2). What information did you base your decision on?

a). What was the source of this information?

b). Was there a delay between the creation of the information and your receipt of it?

6. Funding (15 min)

A. What is the primary consideration in deciding to reprogram funds from one program to another or from one funding classification to another?

1). At what levels are these decisions made?

2). How are decisions made regarding relative funding levels for acquisition vs. operational funds?

a). At what level are the decisions made?

B. What is the primary consideration when deciding to request supplemental funds?

1). At what levels are the decisions made?

C. What is the primary consideration when there are not enough funds available for all needed programs?

D. How do you feel budgeting for risk going to be received by DoD, OMB, and Congress?

7. Give an example of a well managed acquisition program (10 min)

A. What specific characteristics highlight the strengths of the program?

B. Does the program have a primary weakness?

8. What do you see as the role of Congress in the acquisition process? How much do they influence the process? (5 min)

9. Do you feel that the efficiency or effectiveness of program management can be changed by pressure exerted by SecDef or DoD?

A. If so, how much (%) improvement would be the maximum that could be expected under great pressure?

B. If interest or pressure is not felt by the program management, does efficiency suffer?

1). What would be the maximum amount when compared to a "good" program?

10. Summarization and Outbrief (3 min)

Interview Guide (follow-on)

I. Introduction

A. Overview of what we have done since last trip.

1. redefined the macro model
2. developed, programmed, and tested the four sectors

B. Purpose of this trip.

1. to discuss views the strengths and weaknesses of the model to be used in further development.
2. to collect quantitative information on selected relationships within the model.
3. to build confidence in the ability of the model to be useful for analysis.

II. Discussion.

A. Concept of our modeling approach: to capture the structure and basic relationships of the acquisition process. This often requires the use of surrogates that are representative of the decision structure when looking at the aggregate as opposed to individual program decisions.

B. Research and development structure.

1. Review causal diagram of R & D sector. Discuss appropriateness of decision structure at;

a.) New starts - function of perceived capability gap and forecast production terminations.

approve or change needed

b.) DSARC II - function of the minimum of desired approvals or approvals limited by FSD funding (ie outflow of FSD). <u>Discuss use of surrogate of outflow of FSD program units as funding availability.</u>

approve or change needed

c.) Production decision - function of same as DSARC II plus availability of funds for progress in FSD.

approve or change needed

2. Can the cost of R&D be estimated by use of "level of effort" costing? ie. as programs stretched reduce cost linearly in proportion to stretch.

a.) Concept Exploration:

b.) Demonstration and Validation:

C.) Full Scale Development:

Can FSD be "pushed" and at what cost?

3. Are inflation and stretch-out the key factors that affect pricing in concept and validation phases?

C. R & D Data collection:

1. Does the *Defense Science Board analysis of* cancellation rate as a function of time in R&D phase represent conditions today? (show diagram)

2. What percentage of total life cycle cost is spent in each of these phases:

Concept exploration _____
Demonstration and Validation ____
Full scale development _____
Production _____
Operations and support _____

a.) How does the level of technology being attempted affect these percentages?

3. What percentage of time is spent in each R&D phase?

Concept exploration _____
Demonstration and validation _____
Full scale development _____

a.) Does the level of technology being attempted affect these percentages?

D. Effects of technology.

1. Introduce the levels of technology in programs from the Rand Report. Do you feel this representation is reasonable?

2. When technology is "pushed" do we get more capability for the dollar?

3. Do we end up with as much total capability from the program with a "push" as without?

4. Define the expected cost tradeoffs in time for the various options of technology in programs? (see charts)

5. Define the expected cost tradeoffs in dollars for FSD, production, and per year operations and support. (see charts)

E. Production Structure.

1. Is it appropriate to view the purchase of weapon systems in terms of capability purchased or units of production (for example, number of airplanes or tanks)?

a.) How are they viewed during the concept phase and does the level of technical sophistication of the weapon system impact the number purchased (planned)?

2. When production funds available are less than the desired level, with what relative frequency will the following be done:

cancel programs ______
stretch out the planned buy ______
reduce the size of the system buy ______
other _____ define?

b.) Is there a "break point" between options?

F. Financial structure.

1. To what degree do the following factors influence the total amount of funds in the outyears of the Five Year Defense Program?

a. total requirements as a percent of GNP _____
b. percent growth in DoD budget per year _____
c. Are there others? If so, what are they?

2. When programs are stretched due to funding constraints, does the DoD request enough money to put the programs back on the original schedule in succeeding years, or just enough to prevent further slippage?

3. If ten billion dollars were cut from the DoD budget, how much of the cut would be taken from each of the following areas?

a. _____ concept exploration
b. _____ demonstration and validation
c. _____ full scale development
d. _____ production
e. _____ operations and support

4. Can the fraction of the budget that Congress approves for the DoD be predicted as a function of the perceived capability difference between the US and its adversaries, the pressure for non-defense spending (which is seen primarily as a function of the state of the economy), and the fraction of the GNP which is being requested for defense?

a. If not, what other factors do you consider to be better predictors?

b. Can the pressure for non-defense spending be modeled as a function of "real" GNP growth and inflation? If not, what would be better surrogates?

c. Can any of the three factors above dominate the others?

5. Of the three categories of funds, Research and Development, Procurement, and Operations and Support, is there a relative difference in priority? If there are not enough funds to cover all requested amounts, does any one of the three categories suffer more than the others?

6. Does the DoD ever request supplemental appropriations to cover unexpected inflation or cost growth in R&D and production programs, or are supplemental appropriations requests normally only for such things as the rapidly rising fuel costs experienced in recent years?

G. Financial Data.

1. How long does it normally take Congress to act on supplemental appropriations requests?

2. As a percent of the total, how large does the shortfall have to be before a supplemental is requested?

3. How late in the fiscal year can a supplemental request still be entertained?

H. Capability Structure.

1. According to a 1979 Rand study, an accumulation over several years of Soviet defense spending can be used as a reasonable surrogate for their military capability. Do you think this is a reasonable surrogate for use in determining the relative threat level for use in modeling the appropriations and new start decision processes?

a. If not, can you suggest a better surrogate for the overall enemy capability?

2. According to the same Rand study, the CIA estimates for Soviet defense spending are in US dollars, based upon what the US would have to spend to achieve the same results. Assuming that the enemy capability is proportional to enemy defense spending, is it therefore reasonable to assume that the Soviets get about the same amount of capability per dollar spent as the US?

3. Is it reasonable to model the Soviet fraction of GNP spent on defense as a function of their perception of the threat posed to them by the US? If not, what do you think are the primary influences?

I. Capability Data.

1. Where can I find out what the historical range of Soviet defense spending as a percent of GNP has been?

2. How long does it take for changes in the relative capability between the US and USSR to be felt by the DoD? By the Congress?

III. Outbrief.

APPENDIX C

VARIABLE LISTING

R&D Sector Variables

Variable Name	Variable Description	Units of Measure
ADDUR	Adjusted Development Duration	months
ARDFAF	RDFAF Adjusted to include Mgmt. Res.	dimensionless
ARDFF	RDFF Adjusted to include Mgmt. Res.	dimensionless
AVDUR	Adjusted Validation Duration	months
BDCOST	Baseline Development Cost	$/program/ month
BDDUR	Baseline Development Duration	months
BVCOST	Baseline Validation Cost	$/program/ month
CCF	Concept Cancellation Factor	fraction/ month
CCNX	Concept Cancellation Rate	programs/month
CCOST	Concept Phase Cost Factor	$/program/ month
CDUR	Concept Duration	months
CNX	Table of R&D Cancellation Factors	fraction/ year
CP	Concept Programs	programs
CPC	Concept Program Completions	programs/month
CSPRC	Cost Slope for R&D Program Contraction	dimensionless
CSPRSO	Cost Slope for R&D Program Stretch-out	dimensionless
DAFD	Development Affordability	programs/month
DCEF	Development Cost Expenditure Factor	$/program
DCF	Development Cancellation Factor	fraction/month
DCM	Development Cost Multiplier	dimensionless

DCNX	Development Cancellation Rate	programs/month
DCOST	Development Cost	$/program/ month
DDUR	Development Duration	months
DDURR	Development Ratio of Current Duration to Expected Duration	dimensionless
DP	Programs in Development	programs
DPFAQ	DoD Pressure for Acquisition	dimensionless
DS	Development Starts	programs/month
DSLP	Development Cost Slope for the existing DDURR	dimensionless
EDCR	Expected Development Completion Rate	programs/month
EDDUR	Expected Development Duration	months
EVDUR	Expected Validation Duration	months
EVCR	Expected Validation Completion Rate	programs/month
INF	Inflation Factor	fraction/month
MRSF	Management Reserve Spending Factor	dimensionless
OPF	Overprogramming Factor	dimensionless
PA	Production Approvals	programs/month
PAFD	Production Approval Affordability Constraint	programs/month
PDCR	Potential Development Completion Rate	programs/month
PRD	Pressure for R&D	dimensionless
PT	Production Terminations	programs/month
RDCS	R&D Cost Slope for adjusting for funds available	dimensionless
RDCSA	R&D Cost Slope for adjusting for funds available with mgmt. res.	dimensionless
RDFAF	R&D Funds Availability Factor	dimensionless

RDFF	R&D Funds Factor	dimensionless
TECHAR	Technological Advancement Rating	dimensionless
TRDTG	Time Required for Desired Technology Growth	months
TVDUR	Table of Validation Durations for Initializations	months
TVP	Table of Validation Programs for Initializations	programs
VAFD	Validation Start Affordability Constraint	programs/month
VCEF	Validation Cost Expenditure Factor	$/program/month
VCF	Validation Cancellation Factor	fraction/month
VCM	Validation Cost Multiplier	dimensionless
VCNX	Validation Cancellation Rate	programs/month
VCOST	Validation Cost	$/program/month
VDUR	Validation Duration	months
VDURR	Validation Ratio of Duration to Expected Duration	dimensionless
VP	Validation Programs	programs
VS	Validation Starts	programs/month
VSLP	Validation Cost Slope for calculating cost of validation from VDUR	dimensionless
WSCF	Weapon System Complexity Factor	dimensionless

Production Sector Variables

Variable Name	Variable Description	Units of Measure
APFAF	PFAF Adjusted to include Mgmt. Res.	dimensionless
APFF	PFF Adjusted to include Mgmt. Res.	dimensionless
BPD	Baseline Production Duration	months
CAPIP	Capability in Production	capability
CPP	Capability per Program	capability
DMODS	Desired Modification Starts	capability/ month
DPFAQ	DoD Pressure for Acquisition	dimensionless
DROP	Desired Rate of Production	capability/ program/month
EPD	Expected Production Duration	months
FMODT	Force Modernization Time	months
INF	Inflation Fraction	fraction/month
MODC	Modification Completions	capability/ month
MODIP	Modifications in Progress	capability units
MODS	Modification Starts	capability/ month
MODTGF	Modification Technology Gap Fraction	dimensionless
MRSF	Management Reserve Spending Factor	dimensionless
MTIME	Modification Delay Time	months
NFC	Numerical Force Completion Rate	production units/month
NIP	Number of units in Production	production units
NMODT	Normal Modification Time	months

NOBS	Numerical Obsolescence Rate	production units/month
OLTIME	Operational Lifetime	months
OPTECH	Operational Technology	capability/ production unit
OTGAP	Operations Technology Gap	capability/ production unit
PA	Production Approvals	programs/month
PCC	Production Capability Completions	capability/ month
PCOST	Production Cost	$/capability
PDUR	Production Duration	months
PECR	Production Efficiency Cost Ratio	dimensionless
PFAF	Procurement Funds Availability Factor	dimensionless
PP	Programs in Production	programs
PROD	Production Rate	production units/month
PRODS	Production Starts	capability/ month
PT	Production Program Terminations	programs/month
PTECH	Technology Applied to Production	capability/ production unit
PTIME	Time for Production	months
ROP	Rate of Production	capability/ month
SOB	Size of the Buy	production units/program
SOF	Size of the Force	production units
TECHAV	Technology Available	technology units
TPECR	Table of Production Efficiency Cost Ratios	dimensionless

TPFF	Table of Procurement Funds Factors	dimensionless
UCAP	US Capability	capability
UOR	U.S. Weapon System Obsolescence Rate	capability/ month

Financial Sector Variables

Variable Name	Variable Description	Units of Measure
APFAF	Production Funds Availability Factor Adjusted to include management reserve	dimensionless
ARDFAF	R&D Funds Availability Factor Adjusted to include management reserve	dimensionless
BDT	Budgetary Delay Time	months
CAPGF	Capability Growth Factor	dimensionless
CCNX	Concept Cancellation Rate	programs/month
CCOST	Concept Cost	$/program/ month
CDUR	Concept Duration	months
CFR	Concept Funds Required	$
CGF	Concept Phase Growth Factor	dimensionless
CP	Concept Programs	programs
CPC	Concept Program Completions	programs
CPFAQ	Congressional Pressure for Acquisition	dimensionless
CPINF	Current Year Projected Inflation	fraction/month
DBGF	Defense Budget as Fraction of GNP	dimensionless
DCEF	Effective Development Cost	$/program/ month
DCNX	Development Cancellation rate	programs/month
DCOST	Development Cost	$/program/ month
DDBR	DoD Budget Request	$
DFR	Development Funds Required	$
DGF	Development Growth Factor	dimensionless

DMODS	Desired Modification Starts	capability/ month
DP	Development Programs	programs
DPFAQ	Defense Pressure for Acquisition	dimensionless
DROP	Desired Rate of Production	production units/month
EDCR	Expected Development Completion Rate	programs/month
EDDUR	Expected Development Duration	months
EPD	Expected Production Duration	months
EVDUR	Expected Validation Duration	months
EVSR	Expected Validation Start Rate	programs/month
FAR	Funds Appropriation Ratio	dimensionless
FPP	Fiscal Policy Pressure on Appropriation	dimensionless
GNPP	GNP Pressure on Appropriations	dimensionless
ICAPGF	Instantaneous Capability Growth Fraction	fraction/month
INF	Actual Inflation Rate	fraction/month
MODC	Modification Completions	capability/ month
MODCF	Modification Cost Factor	dimensionless
MODS	Modification Starts	capability/ month
MRF	Management Reserve Factor	dimensionless
MRSF	Management Reserve Spending Factor	dimensionless
OSAR	Operations and Support (O&S) Appropriation Rate	$/month
OSBR	O&S Budget Request	$
OSCF	O&S Cost Factor	$/capability/ month

OSCIR	O&S Cost Inflation Rate	\$/capability/ month/month
OSFA	O&S Funds Available	\$
OSFAF	O&S Funds Availability Factor	dimensionless
OSFR	O&S Funds Required	\$
OSFS	O&S Funds Shortage	\$
OSSA	O&S Supplemental Appropriation	\$/month
OSSR	O&S Spending Rate	\$/month
OSSUPR	O&S Supplemental Request	\$
PAR	Production Appropriation Rate	\$/month
PBR	Production Budget Request	\$
PCC	Production Completion Rate	capability/ month
PCOST	Production Cost	\$/capability
PECR	Production level Efficiency Cost Ratio	dimensionless
PFA	Production Funds Available	\$
PFAF	Production Funds Availability Factor	dimensionless
PFR	Production Funds Required	\$
PFRR	Production Funds Required for Remainder of year	\$
PGF	Production Growth Factor	dimensionless
PINF	Projected Inflation factor	dimensionless
PNDF	Pressure for Non-DoD Funds	dimensionless
PP	Production Programs	programs
PRD	Pressure for R&D	dimensionless
PRODS	Production Starts	capability/ month
PRR	Production Reserve Required	\$

PSR	Production Spending Rate	$/month
PT	Production Terminations	programs/month
PTECH	Technology applied in Production	capability/ production unit
RDAR	R&D Appropriation Rate	$/month
RDBR	R&D Budget Request	$
RDFA	R&D Funds Available	$
RDFAF	R&D Funds Availability Factor	dimensionless
RDFR	R&D Funds Required in budget year	$
RDFRR	R&D Funds Required for Remainder of year	$
RDRR	R&D Required Reserve	$
RDSR	R&D Spending Rate	$/month
RGNPGF	"Real" GNP Growth Fraction	fraction/month
STIME	Smoothing Time for program growth factors	months
TECHAR	Technology Advancement Rating	dimensionless
TFPP	Table of Fiscal Policy Pressure	dimensionless
TGNPP	Table of GNP Pressure on Appropriations	dimensionless
TIEFP	Table of Inflation Effect on Fiscal Policy	dimensionless
TIEND	Table of Inflation Effect on Pressure for Non-Defense Funds	dimensionless
TP	Threat Pressure	dimensionless
TPNDF	Table of Pressure for Non-DoD Funds	dimensionless
TRFY	Time Remaining in Fiscal Year	months
TTP	Table of Threat Pressures	dimensionless
UCAP	US Capability	capability

UGNP	US GNP	$
UGNPGF	US GNP Growth Fraction	fraction/month
UGNPGR	US GNP Growth Rate	$/month
UOR	US Obsolescence Rate	capability/ month
VCEF	Validation Effective Cost Factor	$/program/ month
VCNX	Validation Cancellation rate	programs/month
VCOST	Validation Cost	$/program/ month
VFR	Validation Funds Required	$
VGF	Validation Growth Factor	dimensionless
VP	Validation Programs	programs

Technology Sector Variables

Variable Name	Variable Description	Units of Measure
AVETGR	Average Technology Growth Fraction	dimensionless
DTG	Desired Technology Growth factor	dimensionless
FAR	Funds Appropriation Ratio	dimensionless
NTGF	Normal Technology Growth Fraction	fraction/month
PDUR	Production Duration	months
PTECH	Technology Applied to Production	capability/ production unit
TAR	Technology Application Rate	technology units/month
TBTG	Time Between Technology Generations	months
TDR	Technology Discovery Rate	technology
TDTG	Table of Desired Technology Growth vs Technology Advancement Rating	dimensionless
TECHAP	Technology Applied	technology units
TECHAR	Technology Advance Rating	dimensionless
TECHAV	Technology Available	technology units
TECHGF	Technology Growth Fraction	fraction/month
TGAP	Technology Gap between Avail. & Applied	technology units
TGAPF	TGAP as Fraction of TECHAV	dimensionless
TRDTG	Time Required for Desired Technology Growth	months
TTAT	Table of Technology Application Time	months
VDUR	Validation Duration	months
WSCF	Weapon System Complexity Factor	dimensionless

Note: Units of technology correspond to units of capability obtained from a unit of production

Note: A generation of technology is a doubling of the capability obtained from a unit of production

Capability Sector Variables

Variable Name	Variable Description	Units of Measure
ALES	Average Life of Enemy Systems	months
CCOST	Concept Cost	$/program/ month
CDUR	Concept Duration	months
CP	Concept Programs	programs
CPCU	Cost Per Capability Unit for Enemy	$/capability
CPFAQ	Congressional Pressure for Acquisition	dimensionless
CPP	Capability per Program	capability
CPPFAQ	Congressional Perceived Pressure for Acquisition	dimensionless
DCOST	Development Cost	$/program/ month
DIBP	Defense Industrial Base Pressure	dimensionless
DP	Development Programs	programs
DPFAQ	DoD Pressure for Acquisition	dimensionless
DPPFAQ	DoD Perceived Pressure for Acquisition	dimensionless
EADJT	Enemy Capability Adjustment Time	months
ECAP	Enemy Capability	capability units
ECAPGF	Enemy Capability Growth Factor	factor/month
ECAPGR	Enemy Capability Growth Rate	capability units
EDDUR	Expected Development Duration	months
EGNP	Enemy GNP	$
EGNPFA	Enemy GNP Fraction for Acquisition	dimensionless

EGNPGF	Enemy GNP Growth Fraction	fraction/month
EGNPGR	Enemy GNP Growth Rate	$/month
EINT	Enemy Intelligence Delay Time	months
EPD	Expected Production Duration	months
EVDUR	Expected Validation Duration	months
FECAP	Forecast Enemy Capability	capability
FUSCC	Forecast US Capability Completions	capability
INF	Inflation fraction	fraction/ month
MODC	Modification Completions	capability/ month
NGNPFA	"Normal" Enemy GNP Fraction for Acquisition	dimensionless
PCOST	Production Cost	$/capability unit
PECG	Pressure for Enemy Capability Growth	dimensionless
PH	Planning Horizon	months
PP	Production Programs	programs
PRD	Pressure for R&D	dimensionless
PRPRD	Perceived Raw Pressure for R&D	dimensionless
RPECG	Raw Pressure for Enemy Capability Growth	dimensionless
RPFAQ	Raw Pressure for Acquisition	dimensionless
RPRD	Raw Pressure for R&D	dimensionless
TCPP	Time for Congress to Perceive Threat	months
TDPP	Time for DoD to Perceive Threat	months
TPECG	Table of Pressure for Enemy Capability Growth	dimensionless
UCAP	US Capability	capability

UINT	US Intelligence delay time	months
UOR	US Obsolescence Rate	capability units/month
VCOST	Validation Cost	$/program unit/month
VP	Validation Programs	programs

APPENDIX D

MODEL LISTING

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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                      RESEARCH AND DEVELOPMENT SECTOR
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                   ********* CONCEPT PHASE **********

R   NS.KL=((PRD.K-1)*2+1)*SMOOTH(PT.JK,12)*OPF.K*SMOOTH(RDFAF.K,12)       RD1
N      NS=9.67
A       OPF.K=1+CCF.K*CDUR+VCF.K*EVDUR.K+DCF.K*EDDUR.K                    RD2
R     CCNX.KL=CP.K*CCF.K+CLIP(0,CPC.K-VAFD.K,VAFD.K,CPC.K)                RD3
N        VAFD=9.64
A       CCF.K=TABLE(CNX,CDUR,12,240,12)/12                                RD4
T        CNX=.003,.025,.035,.046,.033,.036,.052,.065,
X         .071,.075,.077,.08,.083,.086,.089,.092,.095,.098,
X         .101,.104                                                       RD5
R     VS.KL=MIN(VAFD.K,CPC.K)                                             RD6
A       CPC.K=CP.K/CDUR                                                   RD7
C       CDUR=12                                                           RD8
A       VAFD.K=PRD.K*SMOOTH(VCNX.JK+DS.JK,12)                             RD9
L   CP.K=CP.J+DT*(NS.JK-(CCNX.JK+VS.JK))                                  RD10
N       CP=116

    CONCEPT COSTING

L   CCOST.K=CCOST.J+DT*(INF.J*CCOST.J)                                    RD11
N     CCOST=4.17E+5

                      ******** VALIDATION ********

R     VCNX.KL=VP.K*VCF.K                                                  RD12
A       VCF.K=TABLE(CNX,CDUR+VDUR.K,12,240,12)/12                         RD13
R     DS.KL=MIN(DAFD.K,PVCR.K)                                            RD14
A       DAFD.K=PRD.K*SMOOTH(DCNX.JK+PA.JK,12)                             RD15
A       EVSR.K=VP.K/EVDUR.K                                               RD16
A       EVDUR.K=DLINF3(TRDTG.K,12)                                        RD17
A       PVCR.K=EVSR.K/MAX(RDFF.K,CLIP(ARDFF.K,1,RDFAF.K,MRSF.K))          RD18
A       RDCS.K=CLIP(CSPRC,CSPRSO,RDFAF.K,1)                               RD19
A       RDFF.K=((1/RDCS.K)-1)/((RDFAF.K/RDCS.K)-1)                        RD20
A       RDCSA.K=CLIP(CSPRC,CSPRSO,ARDFAF.K,1)                             RD21
A       ARDFF.K=((1/RDCSA.K)-1)/((ARDFAF.K/RDCSA.K)-1)                    RD22
C        CSPRC=-.5                                                        RD23
C        CSPRSO=.5                                                        RD24
N        EVDUR=28
L   VP.K=VP.J+DT*(VS.JK-(DS.JK+VCNX.JK))                                  RD25
N      VP=TABLE(TVP,TECHAR,6,14,4)
A       VDUR.K=VP.K/DS.JK                                                 RD26
N       DS=8.44
N        VDUR=TABLE(TVDUR,TECHAR,6,14,4)
```

VALIDATION COSTING

```
A       VCEF.K=VCM.K*VCOST.K                                   RD27
L    BVCOST.K=BVCOST.J+DT*(BVCOST.J*INF.J)                     RD28
A       VCOST.K=BVCOST.K*WSCF.K                                RD29
A       VSLP.K=CLIP(CSPRSO,CSPRC,VDURR.K,1)                    RD30
A       VDURR.K=AVDUR.K/EVDUR.K                                RD31
A       AVDUR.K=VP.K/PVCR.K
A       VCM.K=((VDURR.K-1)*VSLP.K+1)/VDURR.K                   RD32
N     BVCOST=8.93E+5
```

********** DEVELOPMENT PHASE ************

```
N     DP=304
R     DCNX.KL=DP.K*DCF.K                                       RD33
A       DCF.K=TABLE(CNX,CDUR+VDUR.K+DDUR.K,12,240,12)/12       RD34
R     PA.KL=MIN(PAFD.K,PDCR.K)                                 RD35
N       PA=6.68
A       PAFD.K=SMOOTH(PT.JK,12)*DPFAQ.K                        RD36
A       EDCR.K=DP.K/EDDUR.K                                    RD37
A       EDDUR.K=BDDUR                                          RD38
C       BDDUR=36                                               RD39
A       PDCR.K=EDCR.K/MAX(RDFF.K,CLIP(ARDFF.K,1,RDFAF.K,MRSF.K))  RD40
L    DP.K=DP.J+DT*(DS.JK-(DCNX.JK+PA.JK))                      RD41
A       DDUR.K=DP.K/PA.JK                                      RD42
```

DEVELOPMENT COSTING

```
A       DCEF.K=DCM.K*DCOST.K                                   RD43
L    BDCOST.K=BDCOST.J+DT*(BDCOST.J*INF.J)                     RD44
A       DCOST.K=BDCOST.K*WSCF.K                                RD45
A       DSLP.K=CLIP(CSPRSO,CSPRC,DDURR.K,1)                    RD46
A       DDURR.K=ADDUR.K/EDDUR.K                                RD47
A       ADDUR.K=DP.K/PDCR.K
A       DCM.K=((DDURR.K-1)*DSLP.K+1)/DDURR.K                   RD48
N     BDCOST=3.333E+6
```

* *

PRODUCTION SECTOR

* *

******* NEW SYSTEM PRODUCTION *******

```
R     PRODS.KL=PP.K*ROP.K*PTECH.K                              P1
R    PCC.KL=DELAYP(PRODS.JK,PTIME,CAPIP.K)                     P2
C       PTIME=30                                               P3
R     PROD.KL=PP.K*ROP.K                                       P4
R     NFC.KL=DELAYP(PROD.JK,PTIME,NIP.K)                       P5
N       NFC=1562.5
R     NOBS.KL=DELAYP(NFC.JK,OLTIME,SOF.K)                      P6
C       OLTIME=240                                             P7
```

```
A      ROP.K=DROP.K*MIN(PFF.K,CLIP(APFF.K,1,PFAF.K,MRSF.K))          P8
A      PFF.K=TABLE(TPFF,PFAF.K,.2,2.0,.1)                            P9
A      APFF.K=TABLE(TPFF,APFAF.K,.2,2.0,.1)                          P10
T       TPFF=.07,.215,.295,.38,.48,.58,.69,.82,1.0,1.065,1.13,
X       1.19,1.25,1.305,1.36,1.41,1.46,1.51,1.56                     P11
A      DROP.K=SOB.K/EPD.K                                            P12
A      EPD.K=BPD                                                     P13
C       BPD=60                                                       P14
A      SOB.K=CPP/PTECH.K                                             P15
C       CPP=100                                                      P16
R     PT.KL=DELAYP(PA.JK,PDUR.K,PP.K)                                P17
N      PT=6.68
A      PDUR.K=SOB.K/ROP.K                                            P18
N      PDUR=60

      NEW SYSTEM PRODUCTION COSTING

L    PCOST.K=PCOST.J+DT*(PCOST.J*INF.J)                              P19
A      PECR.K=TABLE(TPECR,ROP.K/DROP.K,.1,1.6,.1)                    P20
T       TPECR=1.45,1.4,1.35,1.3,1.25,1.2,1.15,1.1,1.05,1.0,1.05,
X       1.1,1.15,1.2,1.25,1.3                                        P21
N       PCOST=3.5E+6

              ******** FORCE MODIFICATION CALCULATION *******

A      OPTECH.K=UCAP.K/SOF.K                                         P22
A      OTGAP.K=TECHAV.K-OPTECH.K                                     P23
C       MODTGF=.05                                                   P24
A      FMODT.K=NMODT.K/DPFAQ.K                                       P25
C       NMODT=240                                                    P26
A      DMODS.K=SOF.K*OTGAP.K*MODTGF/FMODT.K                          P27
R     MODS.KL=DMODS.K*MIN(PFAF.K,CLIP(APFAF.K,1,PFAF.K,MRSF.K))      P28
R     MODC.KL=DELAYP(MODS.JK,MTIME,MODIP.K)                          P29
N       MODS=62.5
N       DMODS=62.5
C      MTIME=24                                                      P30

                ****** US CAPABILITY COMPUTATION ******

R     UOR.KL=DELAYP(PCC.JK+MODC.JK,OLTIME,UCAP.K)                    P31
N      UOR=625
N      PCC=562.5
```

```
**************************************************
                    FINANCIAL SECTOR
**************************************************

          ****** FUNDING REQUIREMENTS ******

        R&D

A    CFR.K=CP.K*(1+((PRD.K-1)*(BDT+6)/CDUR.K))*
X     CCOST.K*12*(1+PINF.K)*MRF                        F1
C    MRF=1.0                                           F2
A    VFR.K=VP.K*(1+((PRD.K-1)*(BDT+6)/EVDUR.K))*
X     VCOST.K*12*(1+PINF.K)*MRF                        F3
A    DFR.K=DP.K*(1+((PRD.K-1)*(BDT+6)/EDDUR.K))*
X     DCOST.K*12*(1+PINF.K)*MRF                        F4
A    RDFR.K=CFR.K+VFR.K+DFR.K                          F5
A    RDBR.K=DLINF3(RDFR.K,BDT)                         F6
C    BDT=12                                            F7


        PRODUCTION

A   PFR.K=((PP.K*(1+((BPFAQ.K-1)*(BDT+6)/EPD.K)))*PTECH.K*DROP.K
X     +SMOOTH(DMODS.K,STIME)*MODCF)*PCOST.K
X     *12*(1+PINF.K)*MRF                               F8
C    MODCF=1.2                                         F9
A    PBR.K=DLINF3(PFR.K,BDT)                           F10

        O&S

A    OSFR.K=UCAP.K*CAPGF.K**(BDT+6)*OSCF.K*12*(1+PINF.K)     F11
A    CAPGF.K=1+SMOOTH(ICAPGF.K,STIME)                  F12
A    ICAPGF.K=(PCC.JK+MODC.JK-UOR.JK)/UCAP.K           F13
A    OSBR.K=DLINF3(OSFR.K,BDT)                         F14
L  OSCF.K=OSCF.J+DT*OSCIR.JK                           F15
R   OSCIR.KL=OSCF.K*INF.K                              F16
N    OSCF=2.08E+4

        ****** ECONOMIC AND POLITICAL FACTORS ******

A    FAR.K=TP.K*GNPP.K*FPP.K/PNDF.K                    F17
L  UGNP.K=UGNP.J+DT*UGNPGR.JK                          F18
R   UGNPGR.KL=UGNP.K*UGNPGF.K                          F19
A    UGNPGF.K=RGNPGF.K+INF.K                           F20
A    RGNPGF.K=.0025+.0035*SIN(6.283*TIME.K/72)         F21
A    INF.K=INFC                                        F22
C     INFC=0.0                                         F23
A    CPINF.K=.9*INF.K                                  F24
A    PINF.K=(1+.9*INF.K)**(BDT+6)-1                    F25
A    TP.K=TABLE(TTP,CPFAQ.K,.9,2.0,.1)                 F26
```

```
T        TTP=.93,.932,.936,.944,.96,.98,.99,.996,1.0,1.002,1.004,1.005  F27
A       DDBR.K=RDBR.K+PBR.K+OSBR.K                                     F28
A       DBGF.K=(DDBR.K+SUM(OSSUPR.K))/UGNP.K                           F29
A       GNPP.K=TABLE(TGNPP,DBGF.K,.03,.07,.01)                         F30
T        TGNPP=1.005,1.003,1.0,.99,.95                                 F31
A       FPP.K=TABLE(TFPP,RGNPGF.K,-.001,.007,.001)
X        +TABLE(TIEFP,INF.K,-.01,.02,.005)                             F32
T        TFPP=1.0,.994,.988,.984,.98,.976,.974,.972,.97                F33
T        TIEFP=0,0,0,-.002,-.006,-.012,-.02                            F34
A       PNDF.K=TABLE(TPNDF,RGNPGF.K,-.001,.007,.001)                   F35
X        +TABLE(TIEND,INF.K,-.01,.02,.005)
T        TPNDF=1.0,.994,.988,.984,.98,.976,.974,.972,.97               F36
T        TIEND=0,0,0,.02,.06,.012,.02                                  F37
```

****** APPROPRIATION AND EXPENDITURE ******

R&D

```
L   RDFA.K=RDFA.J+DT*(RDAR.JK-RDSR.JK)                                 F38
R     RDAR.KL=RDBR.K*FAR.K/DT*PULSE(1,12-DT,12)                        F39
R     RDSR.KL=CP.K*CCOST.K+VP.K*VCEF.K+DP.K*DCEF.K                     F40
A       RDFAF.K=RDFA.K/RDFRR.K                                         F41
A       ARDFAF.K=(RDFA.K-RDRR.K)/RDFRR.K                               F42
A       RDFRR.K=(((CP.K*CGF.K**(TRFY.K/2)*CCOST.K
X        +VP.K*VGF.K**(TRFY.K/2)*VCOST.K
X        +DP.K*DGF.K**(TRFY.K/2)*DCOST.K)
X        *TRFY.K)*(1+CPINF.K)**(TRFY.K/2))                             F43
A       CGF.K=1+SMOOTH(((NS.JK-(CPC.K+CCNX.JK))/CP.K),STIME)           F44
A       VGF.K=1+SMOOTH(((CPC.K-(EVSR.K+VCNX.JK))/VP.K),STIME)          F45
A       DGF.K=1+SMOOTH(((EVSR.K-(EDCR.K+DCNX.JK))/DP.K),STIME)         F46
C         STIME=12                                                     F47
A       RDRR.K=RDFRR.K*(MRSF.K-1)                                      F48
A       MRSF.K=CLIP(MRF,1,TRFY.K,3)                                    F49
N       RDFAF=1
N       ARDFAF=1
L   TRFY.K=TRFY.J+PULSE(12,12-DT,12)-DT                                F50
N       TRFY=12
```

PRODUCTION

```
L   PFA.K=PFA.J+DT*(PAR.JK-PSR.JK)                                     F51
R     PAR.KL=PBR.K*FAR.K/DT*PULSE(1,12-DT,12)                          F52
R     PSR.KL=PCOST.K*(PRODS.JK*PECR.K+MODS.JK*MODCF)                   F53
A        PFAF.K=PFA.K/PFRR.K                                           F54
N        PFAF=1
A        APFAF.K=(PFA.K-PRR.K)/PFRR.K                                  F55
A       PFRR.K=(((PP.K*PGF.K**(TRFY.K/2))
X        *DROP.K*PTECH.K+DMODS.JK*MODCF)*PCOST.K*TRFY.K
X        *(1+CPINF.K)**(TRFY.K/2))                                     F56
A       PGF.K=1+SMOOTH(((EDCR.K-PT.JK)/PP.K),STIME)                    F57
A       PRR.K=PFRR.K*(MRSF.K-1)                                        F58
```

```
L   OSFA.K=OSFA.J+DT*(OSAR.JK-OSSR.JK)                                F59
R     OSAR.KL=OSBR.K*FAR.K/DT*PULSE(1,12-DT,12)+OSSA.K                 F60
R     OSSR.KL=OSFA.K/TRFY.K                                            F61
A       OSSA.K=SHIFTL(OSSUPR.K,1)*FAR.K                                F62
L   OSSUPR.K(1)=CLIP(0,1,OSFAF.J,.99)*OSFS.J*PULSE(1,4-DT,12)          F63
C       M=7                                                            F64
FOR I=1,M                                                              F65
N       OSSUPR(I)=0                                                    F66
A       OSFS.K=(1-OSFAF.K)*OSFA.K                                      F67
A       OSFAF.K=(OSFA.K+SUMV(OSSUPR.K,2,M))/(UCAP.K*CAPGF.K**(TRFY.K/2)
X        *OSCF.K*TRFY.K*(1+CPINF.K)**(TRFY.K/2))                       F68
N       UGNP=2.0E+12
N       RDFA=TABLE(TRDFA,TECHAR,6,14,4)
N       PFA=31.2E+9
N       OSFA=37.4E+9
```

****

TECHNOLOGY SECTOR

****

```
L   TECHAV.K=TECHAV.J+DT*TDR.JK                                        TE1
R     TDR.KL=TECHAV.K*TECHGF.K                                         TE2
A       TECHGF.K=NTGF.K*FAR.K*(1-TGAPF.K)**2                           TE3
A       NTGF.K=(2**(1/TBTG.K))-1                                       TE4
A       TBTG.K=96                                                      TE5
A       TGAP.K=TECHAV.K-TECHAP.K                                       TE6
N        TECHAP=.8
N        TECHAV=1
A       TGAPF.K=TGAP.K/TECHAV.K                                        TE7
L   TECHAP.K=TECHAP.J+DT*TAR.JK                                        TE8
R     TAR.KL=TGAP.K/TABLE(TTAT,TECHAR,0,20,2)                          TE9
T        TTAT=72,60,48,36,30,24,21,18,16,14,12                         TE10
A       WSCF.K=1+LOGN(TECHAP.K)/LOGN(10)                               TE11
A       AVETGR.K=SMOOTH(TECHGF.K,VDUR.K)                               TE12
A       TRDTG.K=LOGN(DTG.K)/AVETGR.K                                   TE13
A       DTG.K=TABLE(TDTG,TECHAR,0,20,2)                                TE14
T        TDTG=1.01,1.01,1.01,1.05,1.1,1.2,1.5,1.65,1.7,1.75,1.8        TE15
A       PTECH.K=SMOOTH(TECHAP.K,(PDUR.K/2))                            TE16
C     TECHAR=10                                                        TE17
```

****

THREAT SECTOR

****

****** ENEMY CAPABILITY *******

```
L   EGNP.K=EGNP.J+DT*EGNPGR.JK                                         TH1
R     EGNPGR.KL=EGNP.K*EGNPGF.K                                        TH2
A       EGNPGF.K=EGP+INF.K                                             TH3
```

```
C       EGP=.004                                                TH3A
N       EGNP=1.0E+12
A       EGNPFA.K=NGNPFA*PECG.K                                  TH4
C       NGNPFA=.05
A       PECG.K=TABHL(TPECG,RPECG.K,1.0,1.2,.2)                  TH5
T        TPECG=1.0/1.2                                          TH6
A       RPECG.K=(DLINF3(UCAP.K,EINT)-(ECAPGR.JK-EOR.JK)*EADJT)
X        *DLINF3(PRD.K,EINT)/ECAP.K                             TH7
C       EADJT=120                                               TH8
C       EINT=6                                                  TH8A
R      EOR.KL=DELAYP(ECAPGR.JK,ALES,ECAP.K)                     TH9
R      ECAPGR.KL=EGNP.K*EGNPFA.K/CPCU.K/12                      TH10
A       CPCU.K=(CCOST.K*CDUR+VCOST.K*EVDUR.K+DCOST.K*EDDUR.K)/
X        CPP+PCOST.K                                            TH11
C       ALES=240                                                TH11A

            ****** PRESSURE FOR NEW STARTS ******

A       PRD.K=MAX(DIBP,PRPRD.K)                                 TH12
C        DIBP=.9                                                TH13
A       PRPRD.K=DLINF3(RPRD.K,TDPP)                             TH14
A       RPRD.K=1+((FECAP.K-UCAP.K-FUSCC.K)/(CPP*PU.K))          TH15
A       PU.K=CP.K+VP.K+DP.K+PP.K                                TH15A
A       FECAP.K=DLINF3(ECAP.K,UINT)*ECAPGF.K**PH.K              TH16
A       ECAPGF.K=(DLINF3(ECAPGR.JK,UINT)-DLINF3(EOR.JK,UINT))/
X        DLINF3(ECAP.K,UINT)+1                                  TH17
A       FUSCC.K=(CP.K+VP.K+DP.K+PP.K)*CPP+
X         (MODC.JK-UOR.JK)*PH.K                                 TH18
A       PH.K=CDUR+EVDUR+EDDUR.K+EPD.K                           TH19

            *****  PRESSURE FOR ACQUISITION *****

A       RPFAQ.K=DLINF3(ECAP.K,UINT)/UCAP.K                      TH20
A       DPPFAQ.K=DLINF3(RPFAQ.K,TDPP)                           TH21
A       DPFAQ.K=MAX(DIBP,DPPFAQ.K)                              TH22
N       DPFAQ=1
A       CPPFAQ.K=DLINF3(RPFAQ.K,TCPP)                           TH23
A       CPFAQ.K=MAX(DIBP,CPPFAQ.K)                              TH24
C       TDPP=12                                                 TH25
C       TCPP=24                                                 TH26
C       UINT=6                                                  TH27
N       ECAPGR=500
N       PECG=1
N       PRD=1
  ***********************************************************************

        ****** INITIALIZATION CHANGES FOR TECHAR CHANGE ******

T   TVDUR=8.4,28,86
T   TVP=81,270,829
T   TRDFA=13.6E+9,15.6E+9,21.6E+9
```

```
      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                         CALCULATION OF OUTPUT VARIABLES

A  ACQLTH.K=CDUR+DLINF3(VDUR.K,(DDUR.K+PTIME))+
X     DLINF3(DDUR.K,PTIME)+PTIME
NOTE  ACQLTH = Time from program initiation to delivery of first
  production item. (months)  Measured for programs in production.
L  TECAGE.K=LOGN(TECHAV.J/OPTECH.J)/SMOOTH(TECHGF.J,TECAGE.J)
N     TECAGE=120
NOTE  TECAGE = Estimated months between the current production
  technology and when it was the 'state of the art.'
A  CC.K=DLINF3((CCOST.K*CDUR),VDUR.K+DDUR.K+PDUR.K)
A  VC.K=DLINF3((VCEF.K*VDUR.K),DDUR.K+PDUR.K)
A  DC.K=DLINF3((DCEF.K*DDUR.K),PDUR.K)
A  PC.K=PCOST.K*PECR.K*CPP.K
A  PROGC.K=(CC.K+VC.K+DC.K+PC.K)/CPP.K
NOTE  PROGC = Cost per capability unit for programs in production
A  CSTR.K=(CC.K+VC.K+DC.K)/PC.K
NOTE  CSTR = Cost ratio : R&D vs Production

      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

OPT RF
PLOT ACQLTH=L/PROGC=$/CSTR=R/TECAGE=T
PLOT ECAP=E,UCAP=U/RPRD=L,RPFAQ=S
SPEC DT=.5,LENGTH=360,PLTPER=12
RUN
```

APPENDIX E

MODEL INITIALIZATION

In order for a system dynamics model to generate the time-varying behavior of a system, the model must be provided with initial conditions for all levels in the model, and certain rates and auxiliaries. While the program will operate with any choice of initial values, the results are more meaningful if the initial conditions represent a consistent scenario. This section presents, by way of example, a method for obtaining a reasonable set of initial values for model operation. The variables requiring initialization are listed alphabetically, by sector in Table E.1.

Auxiliaries are computed at each time step without regard to their previous value; therefore most of the auxiliaries in Table E.1 may be assigned any reasonable value. The six auxiliary variables listed below all fluctuate around one during model operation, and are assigned initial values of one.

RDFAF = 1
ARDFAF = 1
PFAF = 1
DPFAQ = 1
PECG = 1
PRD = 1

There are three levels in the model which require the same initial values on all model runs, because of the special functions they perform in the model. They are

TRFY = 12 (months)
OSSUPR(I) = 0 ($)
TECHAV = 1 (capability/production unit)

Variable Name		Units	Type
R&D Sector:			
BDCOST	Baseline Development Cost	$/program/month	L
BVCOST	Baseline Validation Cost	$/program/month	L
CCOST	Concept Cost	$/program/month	L
CP	Concept Programs	programs	L
DP	Development Programs	programs	L
DS	Development Starts	programs/month	R
NS	New Starts	programs/month	R
PA	Production Approvals	programs/month	R
VAFD	Validation Affordability	programs/month	A
VP	Validation Programs	programs	L
Production Sector:			
DMODS	Desired Modification Starts	capability/month	A
NFC	Numerical Force Completions	prod. units/month	R
MODC	Modification Completions	capability/month	R
PCC	Production Completions	capability/month	R
PCOST	Production Cost	$/capability unit	L
PDUR	Production Duration	months	A
PT	Production Terminations	programs/month	R
TECAGE	Technological Age of Forces	months	L
Financial Sector:			
ARDFAF	Adjusted R&D Funds Availability Factor	dimensionless	A
OSCF	O&S Cost Factor	$/capability/month	L
OSFA	O&S Funds Available	$	L
OSSUPR	O&S Supplemental Request	$	L
PFA	Production Funds Available	$	L
PFAF	Prod. Funds Avail. Factor	dimensionless	A
RDFA	R&D Funds Available	$	L
RDFAF	R&D Funds Avail. Factor	dimensionless	A
TRFY	Time Remaining in Fiscal Yr.	months	L
UGNP	US Gross National Product	$	L
Technology Sector:			
TECHAP	Technology Applied	capability per production unit	L
TECHAV	Technology Available		L
Threat Sector:			
DPFAQ	DoD Pressure for Acquisition	dimensionless	A
ECAPGR	Enemy Capability Growth Rate	capability/month	R
EGNP	Enemy GNP	$	L
PECG	Pressure for Enemy Capability Growth	dimensionless	A
PRD	Pressure for R&D	dimensionless	A

Table E.1 Variables Requiring Initialization

The technology applied can be assigned any value less the the level of available technology.

The initial cost factors, CCOST, BVCOST, BDCOST, PCOST, and OSCF, were initialized by considering the relationship among these factors in the life-cycle cost of a typical weapon system. From the interviews it was determined that the following relationships exist for life-cycle cost:

Concept Phase	>1%
Validation Phase	2.5%
Development Phase	12.0%
Production	35.0%
Operation and Support	50.0%

Since the cost of a capability unit is purely arbitrary, the life-cycle cost of a capability unit was assumed to be ten million dollars. The life-cycle costs are then broken out as follows:

Concept Phase	$ .05M
Validation	.25M
Development	1.20M
Production	3.50M
Operation and Support	5.00M

To determine the R&D cost factors in dollars per program per month, the capability per program and the duration of each phase is used. For the typical programs to which the above cost ratios apply, the technology advancement rating is approximately ten, which results in a validation duration of 28 months. The cost factors for R&D are therefore

CCOST = (100)(50000)/12 = 417000 $/program/month
BVCOST = (100)(250000)/28 = 893000 $/program/month
BDCOST = (100)1200000)/36 = 3333000 $/program/month

Also,

VDUR = 28 months
EVDUR = 28 months

Production Cost is already in dollars per capability unit,

PCOST = 3500000 $/capability unit

Finally, the O&S cost must be spread over the operational lifetime of the weapon system (240 months). Thus,

OSCF = (5000000)/240 = 20800 $/capability unit/month

The next step is to determine the initial US capability. To do this, the initial value of US GNP is selected, and then the US capability is estimated from the presumed fraction of the GNP that has been invested in weapon systems for the last twenty years (operational lifetime is presumed to be twenty years). For example, if the US GNP is two trillion dollars, and has grown at an average of three percent real growth per year, and the US spent five percent of the GNP on defense for the twenty years, then the US accumulated capability would be

UCAP = (1.5E12)(.05)(20)/E7 = 1.5E+5 capability units
and UGNP = 2.0E+12

The US Capability is a pipeline value, and must be initialized by initializing its input rate.

PCC-MODC = 150000/240 = 625 capability units/month

These rates will have an initial value only for the purpose of assigning an initial value of US capability to the level in the pipeline. Since these are rates, they will be computed for whatever information is in the model at the first

time step. A reasonable division of the 625 capability units per month between modifications and production is to give ten percent to modification and the remainder to production. Therefore,

PCC = 562.5 capability units/month
MODC = 62.5 capability units/month

From the amount of capability, we can initialize the O&S funds available by computing the amount required to operate the initialized capability for one year.

OSFA = (150000)(20800)(12) = $ 37.4E+9

The initial values of the enemy GNP and enemy capability are computed next. Assuming that the enemy GNP was one trillion dollars at time equal zero, and has growth at three percent per year, with five percent of GNP invested in weapons acquisition, the enemy capability would be

ECAP = (776E9)(.05)(20)/5E6 = 155000 capability units

Since enemy capability is a pipeline value, the rate must be initialized,

ECAPGR = 155000/240 = 646 capability units/month

The next values to be computed are the size of the force and the modification start rate. At the normal rate of technology growth, technology applied will have doubled twice in the last twenty years. Since TECHAP is .8 at time zero, the average unit in the force has technology of about

SOF = 150000/.4 = 375000 production units

and

TECAGE = 120 months

The size of the force is a pipeline delay value and must be initialized through the rate

NFC = 375000/240 = 1562.5 production units/month

With the information computed so far, the number of programs in each phase of the acquisition process can now be computed. To begin, the total number of programs is computed using the equation for pressure for R&D, setting PRD equal to one. Thus,

PRD = 1 = 1+((FECAP-UCAP-FUSCC)/(CPP*PU))

and

FECAP = 155000(1+((833-646)/155000))**136 = 182619 capability units

Solving the PRD equation for FUSCC and substituting appropriate values for FECAP and UCAP yields

FUSCC = 182619-150000 = 32619 capability units

Since

FUSCC = (CP+VP+DP+PP)*CPP+(MODC-UOR)*PH

PU = (32619-(62.5-625)*136)/100 = 1091 programs

The number of programs in each phase can be computed using the cancellation factors and durations of the phases. Without considering cancellations, the number of programs in each phase could be determined by dividing the expected duration of the phase by the total expected duration of the four phases and multiplying the result by the total number of programs. However, with cancellations, we must adjust the calculation by considering the total fraction of programs expected to be cancelled in each phase. These

fractions are obtained from the table of cancellation factors, Equation RD5.

Concept Phase	.003
Validation Phase	.182
Development Phase	.261

To initialize the model in equilibrium, each phase must contain enough programs to allow for the expected cancellations in that phase and all succeeding phases. The durations for calculation of the number of programs are therefore adjusted as follows:

Concept Phase	12(1+(.003+.182+.261))	= 17.352
Validation	28(1+(.182+.261))	= 40.404
Development	36(1+.261)	= 45.396
<u>Production</u>	60	<u>= 60.000</u>
Total		=163.152

The number of programs in each phase is therefore

CP = 1091(17.352/163.152) = 116
VP = 1091(40.404/163.152) = 270
DP = 1091(45.396/163.152) = 304
PP = 1091(60/163.152 = 401

From these values, the initial flows between phases can be determined by dividing the number of programs by the duration of the phase. Therefore,

PT = 410/60 = 6.68 programs/month
DS = 304/36 = 8.44 programs/month
VAFD = 270/28 = 9.64 programs/month
NS = 116/12 = 9.67 programs/month

Given the above number of programs, the R&D funds available can be computed.

RDFA = ((116)(417000)+(270)(893000)+(304)*
(3333000))(12) = $ 15.6E+9

Similarly, production and modification funding can be computed, and procurement funds available initialized.

$$PFA = (668+(62.5)(12))(3500000)(12) = \$\ 31.2E+9$$

The initial values computed in this appendix are summarized in Table E.2. The values computed here are simply one example of the endless number of possibilities which could be used to initialize the model. Other assumptions about the initial scenario or the values of policy variables will result in different stes of initial values being required. For example, changing the relative capabilities of the US and the enemy forces at time zero would require the GNPs and enemy GNP growth rate to be adjusted to reflect the new conditions.

R&D Sector:

BDCOST	=	3333000	$/program/month
BVCOST	=	893000	$/program/month
CCOST	=	417000	$/program/month
CP	=	116	programs
DP	=	304	programs
DS	=	8.44	programs/month
NS	=	9.67	programs/month
PA	=	6.68	programs/month
VAFD	=	9.64	programs/month
VP	=	270	programs

Production Sector:

DMODS	=	62.5	capability units/month
NFC	=	1562.5	capability units/month
MODC	=	62.5	capability units/month
PCC	=	562.5	capability units/month
PCOST	=	3.5E+6	$/capability unit
PDUR	=	60	months
PT	=	6.68	programs/month
TECAGE	=	120	months

Financial Sector:

ARDFAF	=	1	
OSCF	=	20800	$/capability/month
OSFA	=	37.4E+9	$
OSSUPR	=	0	$
PFA	=	31.2E+9	$
PFAF	=	1	
RDFA	=	15.6E+9	$
RDFAF	=	1	
TRFY	=	12	months
UGNP	=	2.0E+12	$

Technology Sector:

TECHAP	=	.8	capability units/production unit
TECHAV	=	1	capability unit/production unit

Threat Sector:

DPFAQ	=	1	
ECAPGR	=	646	capability units/month
EGNP	=	1.0E+12	$
PECG	=	1	
PRD	=	1	

Table E.2 Summary of Sample Initial Values

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